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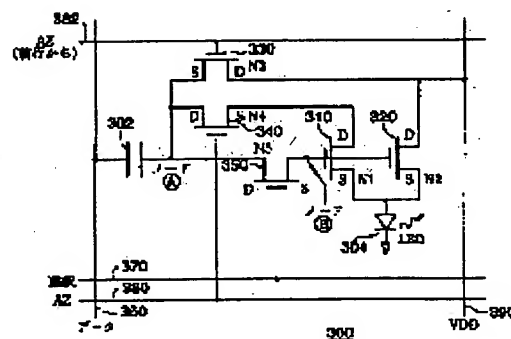
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## (54) ACTIVE MATRIX LIGHT EMITTING DIODE PICTURE ELEMENT STRUCTURE AND METHOD

(57)Abstract:

**PROBLEM TO BE SOLVED:** To reduce unevenness of a current in a light emitting diode(LED) so as to improve uniformity of luminance by composing picture element structure of NMOS transistors, a capacitor and the LED.

**SOLUTION:** Picture element structure 300 is composed of five NMOS transistors 310-350, a capacitor 302 and an LED 304. A selection line 370 is connected to a gate of the transistor 350, and a data line 360 is connected to one terminal of the capacitor 302. An auto-zero line 380 is connected to a gate of the transistor 340, and a VDD line 390 is connected to the drains of the transistors 320, 220. One terminal of the capacitor 302 is connected to the source of the transistor 330 and the drains of the transistors 340, 350, and the sources of the transistors 310, 320 are connected to one terminal of the LED 304. With this constitution, unevenness of a current can be reduced in the LED 304.



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**CLAIMS**

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[Claim(s)]

[Claim 1] It is a display equipped with at least one pixel. The pixel concerned (1) The 1st transistor which has the gate which is an object for the connection to 1st selection Rhine, the source, and a drain, (2) The 1st terminal to which the drain of the 1st transistor concerned is connected, The capacitor which has the 2nd terminal, and the gate which is an object for the connection to (3) auto-zero line, The 2nd transistor which has the drain with which the drain concerned of the 1st transistor concerned is connected with the source, (4) The gate which is an object for the connection to 2nd selection Rhine, and the source connected to the drain of the 2nd transistor concerned, the 3rd transistor which has a drain, and (5) -- with the gate connected to the source of the 1st transistor concerned The 4th transistor which has the drain connected to the source and the source concerned of the 2nd transistor concerned, (6) The gate connected to the source of the 1st transistor concerned, and the source, The 5th transistor which has the drain connected to the drain concerned of the 3rd transistor concerned, (7) Display characterized by the source of the 4th transistor concerned and the source of the 5th transistor concerned consisting of the optical element which has two terminals connected to one terminal.

[Claim 2] The display according to claim 1 said whose optical element is an organic light emitting diode (OLED).

[Claim 3] The display according to claim 1 or 2 said each transistor of whose is a thin film transistor built with amorphous silicon.

[Claim 4] A display given in any of claims 1-3 said whose 2nd selection Rhine is auto-zero lines from the previous line they are.

[Claim 5] It is the display equipped with at least one pixel. The pixel concerned (1) The 1st transistor which has the gate which is an object for the connection to one selection Rhine, the source, and a drain, (2) The 1st terminal to which the drain of the 1st transistor concerned is connected, The capacitor which has the 2nd terminal, and the gate which is an object for the connection to (3) auto-zero line, The 2nd transistor which has the drain with which the drain concerned of the 1st transistor concerned is connected with the source, (4) Diode which has the 1st terminal connected to the source of the 2nd transistor concerned, and the 2nd terminal for connection with lighting Rhine, (5) The gate connected to the source of the 1st transistor, and the source, the 3rd transistor which has the drain connected to the 1st terminal of the diode concerned, and (6) -- the display characterized by the source of the 3rd transistor concerned consisting of the optical element which has two terminals connected to one terminal.

[Claim 6] The display according to claim 5 said whose diode is schottky diode.

[Claim 7] It is the display equipped with at least one pixel. The pixel concerned (1) The 1st transistor which has the gate which is an object for the connection to 1st selection Rhine, the source, and a drain, (2) The 1st terminal to which the drain of the 1st transistor concerned is connected, The capacitor which has the 2nd terminal, and the gate which is an object for the connection to (3) auto-zero line, The 2nd transistor which has the source to which the source concerned of the 1st transistor concerned is connected, and a drain, (4) The gate which is an object for the connection to 2nd selection Rhine, and the source connected to the drain of the 2nd transistor concerned, the 3rd transistor which has a drain, and (5) -- with the gate connected to the source of the 1st transistor concerned The 4th transistor which has the drain connected to the source and the above-mentioned source of the 3rd transistor concerned, (6) The gate connected to the source of the 1st transistor concerned, and the source, The 5th transistor which has the drain connected to the drain concerned of the 3rd transistor concerned, (7) Display characterized by the source of the 4th transistor concerned and the source of the 5th transistor concerned consisting of the optical element which has two terminals connected to one terminal.

[Claim 8] The display according to claim 7 said whose optical element is an organic light emitting diode (OLED).

[Claim 9] The display according to claim 7 or 8 said whose 2nd selection Rhine is an auto-zero line from the previous line.

[Claim 10] (1) at least one auto-zero-ized pixel structure, and (2) -- the display which consists of the auto-zero line connected to the auto-zero-ized pixel structure concerned in order to enable activation of auto-zero-izing at the auto-zero-ized pixel structure concerned, and the 2nd line connected to the auto-zero-ized pixel structure concerned so that one electrical potential difference might be carried to the auto-zero-ized pixel structure concerned, in order to extend the range of (3) auto-zero electrical potential differences.

[Claim 11] The approach which is the approach of turning on the display which has at least one pixel including the circuit which controls the impression energy to an optical element, and is characterized by to consist of the step which auto-zero-izes the (a) pixel, the step which loads data to the pixel concerned via (b) data line, and the step which turns on the optical element concerned based on the data by which (c) preservation was carried out.

[Claim 12] The approach according to claim 11 of containing further the step which precharges said pixel before said auto-zero-ized step (a).

[Claim 13] The approach according to claim 11 or 12 said auto-zero-ized step (a) contains the step which impresses criteria black level.

[Claim 14] The approach which is the approach of turning on the display which has at least one pixel, and is characterized by to consist of the step which adjusts input pixel data based on the pixel parameter by which (a) (b) measurement was carried out with the step which measures the pixel parameter of the pixel concerned, and the step which turns on the pixel concerned based on the input pixel data by which (c) adjustment was carried out.

[Claim 15] The approach according to claim 14 said measurement step (a) measures externally the current pulled out by said pixel.

[Claim 16] The approach according to claim 14 or 15 said adjustment step (b) amends said pixel data using said measured pixel parameter in order to ask for an electrical-potential-difference offset (Voffset) parameter.

[Claim 17] The approach according to claim 16 said adjustment step (b) amends said pixel data further using said measured pixel parameter in order to ask for a gain factor (C) parameter.

[Claim 18] It is the system which consists of the display which changes from two or more pixels to \*\* when it connects with a display controller and the display controller concerned. Each pixel concerned The gate for connection to (1) 1st selection Rhine, the source and the 1st transistor which consists of a drain, and (2) -- with the 1st terminal connected to the drain concerned of the 1st transistor concerned The capacitor which has the 2nd terminal, and the gate for connection to (3) auto-zero line, The 2nd transistor which has the source connected to the source concerned of the 1st transistor concerned, and a drain, (4) The gate for connection to 2nd selection Rhine, and the source connected to the drain concerned of the 2nd transistor concerned, the 3rd transistor which has a drain, and (5) -- with the gate connected to the source concerned of the 1st transistor concerned The 4th transistor which has the drain connected to the source and the source concerned of the 3rd transistor concerned, (6) The gate connected to the source concerned of the 1st transistor concerned, and the source, the 5th transistor which has the drain connected to the drain concerned of the 3rd transistor concerned, and (7) -- the system characterized by the source of the 4th transistor concerned and the source of the 5th transistor concerned consisting of the optical element which has two terminals connected to one terminal.

[Claim 19] (1) the measurement module for measuring the pixel parameter of a pixel, and (2) -- the display controller who has a store for saving the measured pixel parameter concerned, and (3) -- the system which consists of the display connected to the display controller concerned in order to display the input pixel data adjusted based on the saved pixel parameter concerned.

[Claim 20] The system according to claim 19 which has a current detecting circuit for said measurement module to measure the current pulled out by said pixel.

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## DETAILED DESCRIPTION

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### [Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to active-matrix light emitting diode pixel (pixel) structure. This invention relates to the actuation approach of the pixel structure of reducing the heterogeneity of a current in the light emitting diode of pixel structure, and improving the homogeneity of brightness in detail, and said active-matrix light emitting diode pixel structure. In addition, this application is the U.S. \*\*\*\*\* of September 29, 1997 application. 060 60/386 Number and U.S. \*\*\*\*\* of September 29, 1997 application 060 60/387 If the priority of a number is asserted, to \*\*, it will quote at this application.

[0002]

[Description of the Prior Art] The matrix display which turns on a pixel using matrix addressing as shown in drawing 1 is common knowledge in the technical field concerned. The typical display 100 has, the screen element (pixel) 160, i.e., the display element, constituted by the row and column. This display contains the string data generator 110 and the line data generator 120. While sequential energization of each line is carried out through line Rhine 130 in actuation, the pixel which corresponds using corresponding train Rhine energizes. In a passive matrix display, although one pixel of each line is turned on at a time one by one, in an active matrix display, data are loaded to the pixel of each train one by one. That is, although "each train of a passive matrix display is only in an energization condition in a part of all mere frame time", what each train of an active matrix display "is made into an energization condition for" over the whole frame time is made.

[0003] Various play techniques (LCD), for example, a liquid crystal display, and a light emitting diode display (LED) came to be used with spread of a portable display, for example, a laptop computer. It is important to save the power of the portable system which uses a display in a portable display generally, and to enable it to extend the "time" of a portable system by it.

[0004] In LCD, the back light is turned on over the whole term of a display in use. That is, in order to turn on all the pixels in LCD and to make a certain pixel "dark", the light which passes along a pixel is interrupted in a polarization layer. On the other hand, a LED display abolishes the need of only the energized pixel being turned on and turning on a dark pixel, and is planning power saving.

[0005] The active-matrix LED pixel structure 200 of the conventional technique of having two NMOS transistors N1 and N2 in drawing 2 is shown. In this pixel structure, by energizing to a transistor N1, data (electrical potential difference) are first saved to Capacitor C, then, it energizes to the "drive transistor" N 2, and LED is turned on. Although electricity can be saved also for the display which used the pixel structure 200, with this pixel structure, an uneven intensity level is presented according to some causes.

[0006] In the first place, it is observed that the brightness of LED is proportional to the current passing through that. During use, since the threshold voltage of the "drive transistor" N 2 carries out a drift, the current which passes along LED may change. Change of this current serves as a cause of the heterogeneity of the brightness of a display.

[0007] Another cause of the heterogeneity of the brightness of a display can be found [ second ] out in manufacture of the "drive transistor" N 2. In some cases, homogeneous reservation of the initial threshold voltage of a transistor is made from a difficult ingredient, consequently the "drive transistor" N 2 is changed for every pixel.

[0008] The electrical parameter of LED may also present [ third ] heterogeneity. For example, under bias temperature stress conditions, the increment in the turn-on electrical potential difference of OLED (organic light emitting diode) is expected.

[0009] Therefore, the pixel structure of reducing the heterogeneity of the current resulting from fluctuation

of the threshold voltage in the "drive transistor" of pixel structure, and the approach relevant to it are needed in the technical field concerned.

[0010]

[Problem(s) to be Solved by the Invention] This invention aims at offering the LED (or OLED) pixel structure of improving the homogeneity of brightness by reduction of the heterogeneity of the current in the light emitting diode of pixel structure, and an approach.

[0011]

[Means for Solving the Problem] In order to solve the above-mentioned technical problem, this invention persons came to complete a header and this invention for the ability of five NMOS transistors, a capacitor, and the pixel structure that consists of LED to solve the above-mentioned technical problem, as a result of inquiring wholeheartedly.

[0012] The first summary of this invention is a display equipped with at least one pixel. Namely, the pixel concerned (1) The 1st transistor which has the gate which is an object for the connection to 1st selection Rhine, the source, and a drain, (2) The 1st terminal to which the drain of the 1st transistor concerned is connected, The capacitor which has the 2nd terminal, and the gate which is an object for the connection to (3) auto-zero line, The 2nd transistor which has the drain with which the drain concerned of the 1st transistor concerned is connected with the source, (4) The gate which is an object for the connection to 2nd selection Rhine, and the source connected to the drain of the 2nd transistor concerned, the 3rd transistor which has a drain, and (5) -- with the gate connected to the source of the 1st transistor concerned The 4th transistor which has the drain connected to the source and the source concerned of the 2nd transistor concerned, (6) The gate connected to the source of the 1st transistor concerned, and the source, The 5th transistor which has the drain connected to the drain concerned of the 3rd transistor concerned, (7) The source of the 4th transistor concerned and the source of the 5th transistor concerned consist in the display characterized by consisting of the optical element which has two terminals connected to one terminal.

[0013] In the desirable mode of the 1st summary, pixel structure consists of three transistors and one diode.

[0014] In other desirable modes of the 1st summary, pixel structure is different pixel structure of having five transistors.

[0015] Pixel structure is equipped with one Rhine of the addition which extends the auto-zero-ized electrical-potential-difference range in other desirable modes of the 1st summary.

[0016] The 2nd summary of this invention measures a pixel parameter, and consists in one external measurement module which adjusts input pixel data using it, and various measuring methods.

[0017]

[Embodiment of the Invention] Hereafter, this invention is explained in detail using a drawing. In addition, in order to make an understanding easy, the element common to each drawing attached the same possible sign.

[0018] Drawing 3 is the schematic drawing of the active-matrix LED pixel structure 300 by this invention. In a desirable embodiment, active-matrix LED pixel structure is carried out using the transistor made using the thin film transistor (TFT), i.e., polish recon, or the amorphous silicon. Similarly, organic light emitting diode (OLED) is used for active-matrix LED pixel structure in a desirable embodiment. Although this pixel structure is carried out using a thin film transistor and an organic light emitting diode, even if this invention uses other transistors and light emitting diodes of a type, it can be carried out.

[0019] This pixel structure 300 offers a uniform current drive, even when [ that the heterogeneity of transistor threshold voltage ( $V_t$ ) is large and ] the heterogeneity of an OLED turn-on electrical potential difference is large. That is, it is desirable to maintain at homogeneity the current which passes along OLED, and to secure the homogeneity of the brightness of a display by it.

[0020] When drawing 3 is referred to, the pixel structure 300 consists of five NMOS transistors N1 (310), N2 (320), N3 (330), N4 (340), and N5 (350), a capacitor 302, and LED (OLED) (optical element)304 (optical element). Selection Rhine 370 is connected to the gate of a transistor 350. The data line 360 is connected to one terminal of a capacitor 302. The auto-zero line 380 is connected to the gate of a transistor 340. VDD Rhine 390 is connected to the drain of transistors 320 and 330. The auto-zero line 382 from the continued line in a pixel array is connected to the gate of a transistor 330.

[0021] It should note being able to carry out the auto-zero line 382 from the previous line as 2nd selection Rhine. That is, the timing of a current pixel can be used without the auto-zero line 382 from the previous line needing the 2nd selection Rhine, and reduces the current complexity and the cost of a pixel by it.

[0022] One terminal of a capacitor 302 is connected to the source of a transistor (setting to Node A) 330, and the drain of transistors 340 and 350. The source of a transistor 350 is connected to the gate of transistors

(setting to Node B) 310 and 320. The drain of a transistor 310 is connected to the source of a transistor 340. Finally, the source of transistors 310 and 320 is connected to one terminal of LED304.

[0023] As mentioned above, the drive of an organic LED display has many problems by various heterogeneity. This invention relates to the structure of the organic LED display for these problems. That is, each LED pixel is driven by the insensible approach to fluctuation of an LED turn-on electrical potential difference, or fluctuation of TFT threshold voltage. That is, the auto-zero-ized approach used in order to cope with fluctuation of an LED turn-on electrical potential difference or TFT threshold voltage can be used for the present pixel, and it can ask for an offset voltage parameter.

[0024] Furthermore, data are supplied to each pixel as a data electrical potential difference by the approach extremely similar to the approach used in the conventional active-matrix liquid crystal display. Consequently, external or built-in can also be used for the display structure of this invention to the scanner of the conventional row and column.

[0025] Five TFT(s), one capacitor, and LED are used for the pixel of this invention. Connection of TFT is not at the cathode of LED, it should note connecting with an anode and this is needed by the fact that ITO is a hole emitter in organic [ conventional / LED ]. Therefore, LED is not at the drain of TFT and is connected to the source. The train of each display has two line Rhine (an auto-zero line and selection Rhine), and 1-1 / 2 train Rhine (a data line and +VDD Rhine shared with the next train). The wave on each Rhine is also shown in drawing 4 . Actuation of a pixel 300 is explained in full detail in three phase, i.e., a three-stage, below.

[0026] The first phase is a precharge phase. The forward pulse on auto-zero (AZ) Rhine of the previous line 382 turns "ON" a transistor 330, and precharges the node A of a pixel to Vdd, +10V [ for example, ]. Next, in order that a data line may write data in the pixel of the previous line, it changes from the base-line value, and returns to the base line. This does not have the net effectiveness to a pixel under consideration.

[0027] The second phase is an auto-zero phase. current AZ Rhine and current SELECT Rhine of a line -- high -- becoming -- transistors 340 and 350 -- "ON" -- carrying out -- transistor N1 The gate of 310 is dropped, an auto-bias is applied to a turn-on electrical potential difference, and a pole hoe \*\*\*\*\* current is passed to LED. In this phase, the sum total of the turn-on electrical potential difference of LED and the threshold voltage of N1 is saved at the gate of N1. Since N1 and N2 approach very much and they can be arranged, those initial threshold voltage is extremely similar. Furthermore, the gate voltage Vgs to the source of these two transistors is the same \*\*\*\*. Since it depends for the drift of the threshold voltage of TFT only on Vgs over all the lives of TFT, it can be considered that the threshold voltage of these devices is followed over all the lives of TFT. Therefore, the threshold voltage of N2 is also saved on the gate. After completion of auto-zero-izing, while an auto-zero line returns to a low (low), selection Rhine is still Huy (high).

[0028] The third phase is a data write-in phase. Data are impressed as an electrical potential difference exceeding a base-line electrical potential difference to a data line, and are written in a pixel through a capacitor. Next, selection Rhine is related with a low, the sum total of return, a data electrical potential difference, a plus LED turn-on electrical potential difference, and the threshold voltage of plus N2 is related with the remaining frames, and it is saved at Node B. It should note being able to use the capacitor from Node B to +Vdd so that the saved data may not be lost by leak.

[0029] In short, a thin current (trickle current) is used during an auto-zero phase, and the turn-on electrical potential difference of LED and threshold voltage of N2 "are measured", and are saved at Node B. This auto-zero phase is essentially actuation in the current drive mode in which a drive current is very small. An increment is given to LED using the data electrical potential difference impressed only after became a write-in phase after an auto-zero phase. Therefore, it can be said that this invention has "a hybrid drive" rather than an electrical-potential-difference drive or a current drive. The hybrid drive approach does not have a fault in an electrical-potential-difference drive and a current drive, and combines both advantage. Fluctuation of the turn-on electrical potential difference of LED and the threshold voltage of TFT is amended completely like the case in a current drive. Since all Rhine on a display is driven with an electrical potential difference to coincidence, it can drive at high speed.

[0030] attention \*\*\*\* -- the increment of the data electrical potential difference impressed to things at a data line 360 is divided between Vgs(es) of N2 (320) and LED rather than appears directly over the LED304 whole. This only means that there is non-line [ from a data electrical potential difference to an LED electrical potential difference ] type mapping. Although this mapping is combined with non-line [ from an LED electrical potential difference to an LED current ] type mapping and the transfer function of a data electrical potential difference to the whole LED electrical potential difference is generated, this is

monotonous and stable over all the lives of a display as mentioned above.

[0031] The transistor (N3, N4, and N5) in the pixel by which a threshold is not amended of the advantage of the present pixel structure 300 is [ only 1 train time amount ] that it is expected that it does not shift to the forge fire which a duty cycle is very short and can be recognized since it becomes ON per frame.

Furthermore, N2 is the only transistor in the present pass of LED. If the transistor by which the series connection was carried out on this pass may degrade display effectiveness, or may generate the problem by non-amended TFT threshold shift and is shared by all the pixels on one train, it may bring about the remarkable cross talk of a lengthwise direction.

[0032] A selection pulse and an auto-zero (AZ) pulse are formed with a line scanner. In addition to a fixed base-line electrical potential difference (arbitration), string data is impressed in the time slot between AZ pulses. On a data line, the downward edge of a selection signal is generated, while data are effective. External [ of either a direct sample type or a chopped lamp type / various kinds of ] or a built-in train scanner can generate data by this timing.

[0033] According to the above-mentioned pixel structure, a large-sized accepting-reality display can be built using organic [ LED ]. or [ of course, / that a display element or the turn-on electrical potential difference of TFT shifts current pixel structure also to the display technique of the arbitration which uses the display element which needs a drive current especially ] -- or when uneven, it can apply.

[0034] Drawing 5 is the schematic drawing of the desirable embodiment of the active-matrix LED pixel structure 500 by this invention. Although this pixel structure 500 is similar to the pixel structure 300 of drawing 3, one schottky diode is being used for it instead of two transistors here.

[0035] Using five transistors per pixel is mentioned as one of the faults which the pixel structure 300 may have. That is, since many transistors are used for each pixel, the fill factor (fill factor) (assuming the bottom side emission which passes along an active plate) of a pixel, and its yield (yield) may also be affected. Therefore, the pixel structure 300 achieves the same function as the above, reducing a transistor count from five pieces to each pixel at three pieces only using one schottky diode.

[0036] In drawing 5, a pixel 500 consists of the schottky diode 540 of 502 or 1 capacitor of three NMOS transistors [ 3 (530) or 1 ] N1 (510), N2 (520), and N, and LED (OLED)550 (optical element). Selection Rhine 570 is connected to the gate of a transistor 530. The data line 560 is connected to one terminal of a capacitor 502. The auto-zero line 580 is connected to the gate of a transistor 520. Lighting Rhine (similar to VDD Rhine) 590 is connected to one terminal of schottky diode 540.

[0037] One terminal of a capacitor 502 is connected to the drain of transistors (setting to Node A) 520 and 530. The source of a transistor 530 is connected to the gate of a transistor (setting to Node B) 510. The drain of a transistor 510 is connected to the source of a transistor 520, and one terminal of schottky diode 540.

[0038] The pixel structure 500 also operates as follows in 3 of a precharge phase, an auto-zero phase, and a data write-in phase phases. Before all lighting Rhine is mutually combined around the display and a precharge phase starts, these lighting Rhine is held at the electrical potential difference VILL of plus of abbreviation +15V. In the following explanation, a line under consideration is called "Line i." The wave on each Rhine is also shown in drawing 6.

[0039] The first phase is a precharge phase. Precharge will be started, if auto-zero (AZ) Rhine turns ON a transistor N2 and selection Rhine turns ON a transistor N3. This phase is performed when a data line is in reset level. Although the electrical potential difference in Nodes A and B rises to the same electrical potential difference as the drain of a transistor N1, this is a diode descent lower than VILL.

[0040] The second phase is an auto-zero phase. Next, lighting Rhine falls to a ground. all the pixels in this phase and on an array -- a short time -- it becomes dark. Here, schottky diode 540 insulates the drain of a transistor N1 from grounded lighting Rhine, and auto-zero-ization of N1 starts. If Node B reaches an electrical potential difference almost equal to the turn-on electrical potential difference of the threshold voltage plus LED 550 of a transistor N1, a transistor N2 will be turned "OFF" using AZ Rhine, and lighting Rhine will return to VILL. All the pixels of the line which was not chosen light up again.

[0041] The third phase is a data write-in phase. Next, the data about Line i are impressed to a data line. The power surge in Nodes A and B makes equal the difference between the reset voltage level of a data line, and a data voltage level. Thus, fluctuation of the threshold voltage of a transistor N1 and the turn-on electrical potential difference of LED is amended. After the electrical potential difference in Node B settles down, a transistor N3 is turned OFF using selection Rhine about Line i, and a data line is reset. A data electrical potential difference suitable to the following frame is saved now at a pixel.

[0042] In the above, although it had the advantage of 5 transistor pixel described previously, 3 transistor pixel for an OLED display with few transistor counts was explained. It is that a separate transistor is used

for auto-zero-izing and an LED drive by 5 transistor pixel as further advantage. In order for a pixel 300 to operate appropriately, it is required for the initial threshold of these two transistors to be in agreement, and to carry out a drift similarly over the whole term of a life. According to the place which the latest experimental data suggests, if the drain electrical potential differences of TFT(s) (they are these transistors like) differ mutually, similarly the drift of both the TFT(s) will not be carried out. Therefore, a pixel 500 performs auto-zero-ization on the same transistor which drives LED so that suitable auto-zero-ization may be guaranteed.

[0043] Drawing 7 is the schematic drawing of the alternative embodiment of the active-matrix LED pixel structure 700 by this invention. Although this pixel structure 700 is similar to the pixel structure 300 of drawing 3, it generates a still more exact auto-zero electrical potential difference.

[0044] That is, in drawing 3, each precharge cycle produces auto-zero-ization from the fact of pouring the big plus charge QPC into the node A of a pixel 300 as shown in drawing 3. The capacitance of all in a precharge phase and on Node A is almost from Capacitor Cdata, and the charge poured into Node A is expressed with a formula (1).

[0045]

[Equation 1]

$$Q_{pc} \equiv C_{data} (V_{DD} - V_A) \quad (1)$$

[0046]  $V_A$  is an electrical potential difference in the node A before a precharge phase starts here.  $V_A$  is influenced by the data beforehand given to the pixel 300, the threshold voltage of N3 (300), and the turn-on electrical potential difference of LED304. Since Cdata is big capacitance (about 1pF), QPC is also as large as 10 picocoulomb (picocoulomb) extent.

[0047] When it is in the auto-zero level by which the pixel 300 was stabilized, QPC flows through N1 (300) and LED304 during an auto-zero phase. Since auto-zero spacing (interval) is short (about 10microsec), a gate pair source auto-zero electrical potential difference higher than the threshold voltage may remain in N1, and LED exceeds and auto-zero-izes the turn-on electrical potential difference similarly. Thus, in an auto-zero-ized process, it is Node A and Node B and not a true zero current auto-zero electrical potential difference but the approximate value may be generated.

[0048] What should be observed is the point that it is not necessary to generate the true zero current auto-zero electrical potential difference corresponding to the exact zero current which passes along N1 and LED. In this invention, it is desirable to obtain the auto-zero electrical potential difference which can pass a feeble current (about 10nanoampere) through N1 300 and LED 304. Since auto-zero spacing (interval) is about 10microsec, QPC must be about 0.1 picocoulomb extent. As mentioned above, QPC(s) are about 10 picocoulombs.

[0049] Thus, as big effectiveness of QPC, the stabilization auto-zero electrical potential difference of a pixel may easily exceed the sum total of threshold voltage and a turn-on electrical potential difference. Over the whole display, if the auto-zero electrical potential difference with this superfluous condition itself is uniform, it will not become a problem. That is, this effectiveness can be coped with by offsetting all data electrical potential differences suitably.

[0050] However, a problem may be produced when it QPC is not only large, but is influenced by a front data electrical potential difference and the front auto-zero electrical potential difference itself. If this condition occurs within a display, the auto-zero electrical potential difference of all pixels not only becomes superfluous sharply, but the magnitude of excess voltage may differ for every pixel. Under such conditions, a uniform display cannot actually be made by auto-zero-ization of a pixel 300.

[0051] Since this problem is coped with, a pixel 700 can lower Precharge QPC to a very small value. Moreover, the "adjustable precharge" approach that QPC can be changed according to a charge actually required for auto-zero-izing is indicated. When a current auto-zero electrical potential difference is too low, in order to, raise an auto-zero electrical potential difference even to a desired value in short, QPC serves as the minimum value and about 0.1 picocoulombs. However, if a current auto-zero electrical potential difference is too high, QPC will become zero substantially and an auto-zero electrical potential difference will be enabled to fall quickly.

[0052] When drawing 7 is referred to, a pixel 700 consists of five NMOS transistors, N1 (710), N2 (720), N3 (730), N4 (740) and N5 (750), a capacitor 702, and LED (OLED)704 (optical element). Selection Rhine 770 is connected to the gate of a transistor 710. The data line 760 is connected to one terminal of a capacitor 702. The auto-zero line 780 is connected to the gate of a transistor 740. VDD Rhine 790 is connected to the drain of transistors 720 and 750. The auto-zero line 782 from the continued line in a pixel array is connected



to the gate of a transistor 750.

[0053] In this invention, it is the description that the auto-zero line from the continued line can be made into second selection Rhine. That is, it can be made the timing which can use the auto-zero line 782 from the continued line, without needing second selection Rhine for the timing of the present pixel, and the present complexity and the cost of a pixel can be reduced.

[0054] One terminal of a capacitor 702 is connected to the drain of a transistor (setting to Node A) 710. It connects with the gate of transistors (setting to Node B) 720 and 730, and the source of a transistor 710 is connected to the source of a transistor 740. The drain of a transistor 740 is connected to the source of a transistor (setting to Node C) 750, and the drain of a transistor 730. Finally, the source of transistors 730 and 720 is connected to one terminal of LED704.

[0055] Furthermore, a pixel 700 is similar to a pixel 300 concretely except a precharge electrical potential difference being impressed to the node C which is the drain of a transistor N3 (730). Furthermore, there is also some timing modification [ like ] shown in drawing 8 . Below, actuation of a pixel 700 is divided into the phase of three phases, and is explained.

[0056] The first phase is a precharge phase performed into the front Rhine time (i.e., before data are impressed to the pixel of the continued line). The pulse of plus on selection Rhine turns "ON" N1, by this, Nodes A and B short-circuit mutually and the condition of a pixel 700 returns to the condition after the last auto-zero phase. That is, a pixel returns to the electrical potential difference independent of data which is the latest guess value of the suitable auto-zero electrical potential difference of a pixel. While N1 is "ON", the forward pulse on the auto-zero line 782 from continued-line Rhine turns "ON" a transistor N5, and precharges Node C to Vdd by this. Next, transistors N1 and N5 are set to "OFF."

[0057] Although ON of transistors N1 and N5 and the relative timing of OFF are not so important, a transistor N1 must be set to ON before a transistor N5 is turned off. Otherwise, a transistor N3 may still serve as as [ ON ] according to the old data electrical potential difference, and the charge poured in to Node C may leak through a transistor N3.

[0058] Charge QPC is saved in Node C after a precharge phase on the capacitance of the gate pair source / drain of transistors N3, N4, and N5. Since the sum total of these capacitance is very small (about 10 fF(s)) and precharge spacing raises Node C by about 10v, QPC(s) are about 0.1 picocoulombs at the beginning. However, this charge is the rate of changing with the approximation precision over the true auto-zero electrical potential difference of a front auto-zero electrical potential difference, and is leaked from Node C before an auto-zero phase. Therefore, for auto-zero-izing, the relation of  $QPC \leq 0.1$  picocoulomb will be more precisely shown according to how much amount of charges saying whether to be the need. This is the adjustable precharge description. When the last auto-zero electrical potential difference is too low, N3 is un-flowing in a precharge phase, and QPC should stop at the maximum and raises an auto-zero electrical potential difference toward the demand level during an auto-zero phase. When the last auto-zero electrical potential difference is too high, N3 flows, QPC will be leaked by the time an auto-zero phase starts, and the sudden fall of an auto-zero electrical potential difference is attained.

[0059] Although the relative timing of transistors N1 and N5 is not important, desirable timing is shown in drawing 8 . In order to make into the shortest time amount which precharge takes, two transistors N1 and N5 are set to ON at coincidence. Although N1 is off before N5, thereby, leak (it is intentional) of QPC from Node C corresponds to the node B electrical potential difference depressed in capacity by turning OFF N1. Thereby, leak of QPC from Node C certainly corresponds to an equal node B electrical potential difference, when zero data are impressed to a pixel.

[0060] In short, a pixel 700 offers the precharge means of the pixel which enables more effective auto-zero-ization as compared with a pixel 300. Specifically, auto-zero-ization of a pixel 700 is an independence to correctness, quickness, and data more. In the check by computer simulation, a pixel 700 has good auto-zero-izing, and the almost fixed OLED current pair data voltage characteristic can be maintained over the whole term of the actuation life of 10,000 hours.

[0061] Drawing 9 is the schematic drawing of the active-matrix LED pixel structure 900 which are other embodiments of this invention. Although the pixel structure 900 is similar to the pixel structure 700 of drawing 7 , it has additional Vprecharge Rhine 992, and the points which can extend the auto-zero electrical-potential-difference range, without raising the LED supply voltage Vdd differ. This additional correction of a pixel improves the life and effectiveness of a pixel.

[0062] Since Vdd is a precharge electrical potential difference, the pixel (200,300,700) explained above has a limit that an auto-zero electrical potential difference cannot exceed Vdd. However, in order that the threshold voltage of transistors N2 and N3 may carry out a drift over the life period of a transistor and may

amend the drift of TFT drift voltage and an OLED turn-on electrical potential difference, the point which will need to make an auto-zero electrical potential difference higher than Vdd is reached. Since an auto-zero electrical potential difference cannot reach a higher electrical potential difference, the homogeneity of a display deteriorates quickly and marks the end of the useful life longevity of a display. If Vdd is made high, a higher auto-zero electrical potential difference can be attained, but since Vdd is also an OLED drive power source, power effectiveness falls victim.

[0063] Furthermore, if Vdd is lowered and a transistor N2 is operated in the Rhine form field for an improvement of power effectiveness, the range of an auto-zero electrical potential difference will be restricted further. (If it is made such, of course, it is necessary to make N2 larger than the case where it is made to operate by the saturation state) Since an auto-zero electrical potential difference needs to reach level higher than Vdd after short-time actuation in this case, a drive life becomes very short.

[0064] If drawing 9 is referred to, the limit to an auto-zero electrical potential difference is lost to a pixel 700, and modification of the option which makes it possible to fully exceed Vdd by it is included in it. The pixel 900 is the same as a pixel 700, except that train Rhine 992 is added and it is connected to the drain of a transistor 950.

[0065] Train Rhine 992 is added to the array in order to carry the DC electrical potential difference Vprecharge to all pixels. These train [ all ] Rhine interconnects at the edge of a display. By raising Vprecharge to level higher than Vdd, a pixel 900 can be precharged and auto-zero-ized on an electrical potential difference higher than Vprecharge. \*\* -- a high value hardly affects display effectiveness.

[0066] Each Vprecharge Rhine 992 should note that the share with the train which a pixel adjoins is possible. This Vprecharge Rhine is run as line Rhine, and the share with an adjoining line is possible for it again.

[0067] In short, in order to extend the range of an auto-zero electrical potential difference exceeding Vdd, the OLED pixel equipped with additional electrical-potential-difference Rhine is indicated. By this, an OLED drive transistor is a required low electrical potential difference on power effectiveness, and it can operate even in the Rhine form field, without restricting an auto-zero electrical potential difference depending on the case. Therefore, a long actuation life and a long well head can be attained. Although this modification was explained about the pixel 700, finally this option modification can carry it out in other auto-zero pixel structures which are not restricted to them including the above-mentioned pixel 200,300.

[0068] although each above-mentioned pixel structure is designed so that the transistor threshold voltage fluctuation and OLED turn-on voltage variation in a pixel may be amended as an object for an OLED display, these pixel structure copes with the heterogeneity generated in the exterior of a pixel -- as -- it is not designed. The usable thing was pointed out to the conventional train drive circuit also after this pixel had united with the display even from the exterior of a display plate.

[0069] Though regrettable, as for an one apparatus data driver, it is common that is not so accurate as an external driver. Although the precision of \*\*12mV can be attained in a commercial external driver, it has become clear in the one apparatus driver that precision of \*\*50mV cannot be attained. An error peculiar to an one apparatus driver type is DC level of a data non-dependency applied to an offset error, i.e., all data electrical potential differences. This offset error changes the value of an ununiformity, i.e., DC level, for every data driver. A liquid crystal display tends to permit an offset error. It is because it is almost exact on the average and a mutual error cannot be recognized by the eye, although a frame drives the reason by sequential antipole nature, an offset error makes liquid crystal dark slightly with a certain frame and it is made bright with the following frame. However, an OLED pixel is driven with single polarity data. Therefore, it does not generate, but if an one apparatus scanner is used, a serious heterogeneity problem may generate bipolar elimination of an offset error.

[0070] Drawing 10 is the schematic drawing of the active-matrix LED pixel structure 300 of this invention connected to the data driver 1010 through the train transistor 1020. This invention explains the elimination approach of the offset error in the one apparatus data scanner for an OLED display. That is, this approach is designed so that it may operate with the pixel of the arbitration which a pixel is connected to a data line in capacity, for example, has an auto-zero phase like the above-mentioned pixels 200,300,500 and 700.

[0071] If drawing 10 is referred to, the above-mentioned pixel 300 is connected to the data line which supplies analog level to a pixel in order to decide the brightness of an OLED element. In drawing 10  $R > 0$ , a data line is driven by the data driver which uses the chopped lamp technique (chopped ramp technique) for setting up an electrical potential difference on a data line. The various sources of an error which generate an offset error on a data line exist in this approach (technique). For example, the time amount from which an electrical-potential-difference comparator changes may be changed according to the maximum slew rate

(slew rate) of a comparator. Moreover, changing the maximum slew rate sharply is observed by experiment. An offset error affects the electrical potential difference saved at the pixel. Since the offset error is uneven again, fluctuation of brightness is brought about over the whole display.

[0072] In this invention, the period of auto-zero-izing for a pixel to eliminate the internal threshold error of itself is used also for the calibration of the offset error of a data scanner. The wave of various Rhine is shown in drawing 11.

[0073] That is, this is attained by setting up criteria black level on a data line using the same train driver as impressing an actual data electrical potential difference. This criteria black level impressed during the auto-zero phase of a pixel is set up on a data line in the completely same way as an actual data electrical potential difference being set up. That is, in the time amount defined by the electrical-potential-difference comparator, the chop of the data lamp (data ramp) is carried out. Therefore, the electrical potential difference which crosses the capacitor C of a pixel becomes settled with the combination which added the offset error electrical potential difference to the turn-on electrical potential difference and black level of a pixel. Criteria black level is maintained during the whole term of an auto-zero phase. If actual data are impressed to a pixel, a data scanner offset error will be eliminated by the electrical potential difference saved on the capacitor of a pixel.

[0074] This technique is applicable not only to the one apparatus scanner which uses a chopped lamp but the scanner which uses a direct sampling to up to a train. When, as for an error, a train (it is big) transistor is turned OFF in a direct sampling, it generates by the ununiformity capacity feed through to the data line of a gate signal. Threshold voltage fluctuation of this transistor produces an ununiformity offset error completely like the ununiformity offset error produced with a chopped lamp data scanner.

[0075] Therefore, this can be amended similarly. Black reference voltage is written in a train during the auto-zero phase of a pixel. Since all a party's pixels auto-zero-ize to coincidence, this black level is written in all data streams at coincidence at the time of the Rhine time initiation. Black level is maintained throughout [ whole term / of an auto-zero phase ]. Like [ in the case of a chopped lamp scanner ], if actual data are impressed to a pixel, an offset error will be eliminated by the electrical potential difference saved at the pixel capacitor. However, a time amount overhead required for amendment of an offset error is considered for there to be [ which uses direct sampling technique ] rather than [ little ] using chopped lamp technique.

[0076] The approach of this invention for amending a data driver error should enable creation of the homogeneous far good organic LED display of brightness rather than the option. The approach explained here and the auto-zero-ized pixel of one of the above can be used, and the brightness homogeneity of 8 bits without degradation which was conspicuous in homogeneity over all the lives of a display can be attained.

[0077] Although the above-mentioned indication described two or more pixel structures which can be used since the heterogeneity of the brightness of a display is coped with, an external means can amend heterogeneity as substitute approach (technique). More specifically, the following indication explains the approach and the external calibration circuit for coping with the heterogeneity of the brightness of a display. In short, the heterogeneity which measured heterogeneity, saved and was measured can be used about all pixels, and the calibration of data (for example, data electrical potential difference) can be performed.

[0078] Thus, in the following explanation, although the conventional pixel structure of drawing 2 is used, the external calibration circuit and approach of this invention can be used for other pixel structures which are not restricted to these including the above-mentioned pixel 300,500,700. However, if heterogeneity is coped with by the external calibration circuit and approach of this invention, easier pixel structure can be adopted as a display and the yield and the fill factor (fill-factor) of a display can be made to increase by it.

[0079] Drawing 12 is the schematic drawing in the condition of having interconnected and having considered the array (set) of a pixel 200 as the pixel block 1200. If drawing 2 is referred to, in the case of actuation, data will be the approach ordinarily performed with an active matrix display, and will be written in a pixel array. That is, by driving selection Rhine highly, the party of a pixel is chosen and an access transistor N1 serves as ON by it. By impressing a data electrical potential difference to each data line, data are written in each pixel of this line. After the electrical potential difference in Node A is stabilized, this line is canceled of selection by driving selection Rhine low. This data electrical potential difference is saved at Node A until this line is chosen with the following frame. Since there is possibility of some charge leaks from Node A and the voltage drop of unsuitable level is prevented while N1 is turned OFF, an accumulation-of-electricity capacitor may be needed for Node A. The broken line in drawing shows the connection method of a capacitor for coping with a voltage drop. However, such sufficient capacitance may exist in relation to the gate of N2 that the capacitor of such an addition is made unnecessary.



[0080] In what should be observed, the brightness L of OLED was proportional to the current I mostly, and its proportionality constant is considerably stable over the whole display surface. Therefore, if the OLED current decided good is generated, a display will become homogeneity visually.

[0081] However, a pixel is supplied the gate voltage on not an OLED current but N2 by the program. TFT threshold voltage and a mutual conductance (transconductance) may present some initial heterogeneity crossed to the whole display, as the electrical parameter of OLED presents. Furthermore, it is common knowledge that TFT threshold voltage increases under bias temperature stress conditions like an OLED turn-on electrical potential difference. Therefore, these parameters are ununiformities at the beginning, it is a mode depending on each bias hysteresis of each pixel, and it is expected that it changes over all the lives of a pixel. If the program of the gate voltage of N2 is created without amending these parameters, a display will be uneven from the beginning and heterogeneity will increase gradually over all the lives of a display.

[0082] This invention is the approach which the OLED current which the electrical parameter of TFT and OLED was amended and was decided by it good produces in a pixel array. The approach for amending the data electrical potential difference impressed to N2 is explained below.

[0083] Drawing 2 and drawing 12 show the pixel array which has the VDD supply line arranged at juxtaposition at the data line. (In a desirable embodiment, VDD Rhine can wire juxtaposition in selection Rhine.) Thus, a pixel can share each VDD Rhine between two pieces or the adjoining train beyond it, and can reduce the number of VDD Rhine. Drawing 12 shows the condition that VDD Rhine banded together and was blocked around the display. There may be many VDD Rhine included in each pixel block 1200 like the total of VDD Rhine on a display at least as one. However, each pixel block 1200 includes in a desirable embodiment, about 24 VDD Rhine, i.e., the pixel train of about 48.

[0084] Drawing 13 is the schematic drawing of interconnect with a display 1310 and a display controller 1320. A display 1310 consists of two or more pixel blocks 1200. A display controller 1320 consists of the VDD control module 1350, the measurement module 1330 and various I/O devices, for example, an A/D converter, and the memory for saving a pixel parameter.

[0085] Each pixel block is connected to the detection pin (VDD/SENSE) 1210 in the edge of a display, as shown in drawing 12 and 13. During the usual display actuation, the detection pin 1210 is changed to 10 thru/or a 15-volt external Vdd power source, and supplies the current for turning on an OLED element by this to a display. Furthermore, specifically, each VDD/SENSE pin 1210 is connected to the p channel transistors P1 (1352) and P2 (1332) and the current detecting circuit 1334 of a pair in the display controller 1320. During the usual actuation, the ILLUMINATE signal from a display controller operates P1, and connects a VDD/SENSE pin to a Vdd power source. In a typical embodiment, the currents which pass along P1 are expected to be about 1mA / train.

[0086] In order to amend the parameter of TFT and OLED, in order to collect the information about the parameter of each pixel, the external current detecting circuit 1334 is specially operated through a MEASURE signal among a measurement cycle. The collected information is used for the count and adjustment of a data electrical potential difference suitable for realizing a required OLED current during the usual display actuation.

[0087] Furthermore, all other pixels in the measurement cycle of a specific pixel and within a pixel block are turned OFF, and enable it to specifically disregard the drawer of the current from "OFF" pixel certainly by it by impressing a low data electrical potential difference (for example, below zero) to them. Next, the current pulled out by the target pixel is measured according to the impression data electrical potential difference of one or more pieces. A data pattern (that is, it is [ certain ] under block, and only one pixel is ON, in addition all pixels are off) is impressed to a pixel by the usual approach among each measurement cycle, data are impressed to DATA Rhine by the data driver circuit, and one line is chosen at a time. Thus, since a display is divided by two or more pixel blocks, two or more pixels can be measured by turning ON at least one pixel in each pixel block.

[0088] The current pulled out by the object pixel within each pixel block is measured in P2 from the exterior by driving on the level which connects a detection pin to the input of the current detecting circuit 1334 by P2 course while it separates the VDD/SENSE pin 1210 for ILLUMINATE Rhine and MEASURE Rhine from a VDD power source. Pixel currents are expected to be 1 thru/or 10microA. Although the current detecting circuit 1334 is shown in drawing 13 as mutual impedance amplifier, a current detecting circuit can also be carried out with other gestalten. In this invention, amplifier generates the electrical potential difference proportional to the current in an input edge in an outgoing end. These measured information is collected by I/O device 1340, and this information is changed into a digital format there, and it is saved at the calibrations of a data electrical potential difference. The resistor in the current detecting circuit 1334 is

about 1 megohm.

[0089] Although correspondence of a pixel block and one to one has shown two or more current detecting circuits 1334, if multi-PUREKKUSA (un-illustrating [ multi-plexer, ]) is used, the number of current detecting circuits can be reduced. That is, two or more VDD/SENSE pins can be multiplexed to the single current detecting circuit 1334. When extreme, a single current detecting circuit can be used for all displays. Although the complexity of an external circuit can be reduced if a VDD/SENSE pin is multiplexed to a detecting circuit in this way, the display measuring time becomes long.

[0090] Since the usual display actuation must be interrupted in order to perform a pixel measurement cycle, pixel measurement must plan timing so that it may not interfere with those who see as much as possible. Since a pixel parameter changes gradually, it is not necessary to measure a specific pixel frequently, and a measurement cycle can be distributed over a long period of time.

[0091] Although it is not necessary to measure all pixels to coincidence, coincidence measurement is advantageous in order to avoid the heterogeneity based on an adjustable measurement lag (delay). This can be attained by measuring all pixels quickly, when a display module turned [ "turning on" ] on or "is turned off" off. Although it will not become the obstacle of the usual actuation if a pixel is measured when a display module is "OFF", the saved pixel parameter has the fault that homogeneity may not be guaranteed any longer, in long "OFF" period. However, if the power source which is not interrupted is available (setting for example, in screen saver mode), while a display is "OFF" (from a user's viewpoint), a measurement cycle can be performed periodically. Of course, as the option of the arbitration which includes no quick measurement of pixels when a display module is "ON", when power is "OFF", it is required for the nonvolatile memory for saving measurement information to be available.

[0092] If pixel measurement information is available, since the various causes of the heterogeneity of a display will be amended, amendment or the calibration of a data electrical potential difference is applicable to a display. For example, since threshold voltage fluctuation of a transistor and OLED turn-on voltage variation are coped with, a data electrical potential difference can be amended. Therefore, two or more approaches of amending the above and other display heterogeneity are explained below. If these approaches are used, even if some of [ some ] them have the cause of big heterogeneity in a display, a uniform high-definition display can be offered.

[0093] In order to explain this amendment approach, on a display, it is assumed that it is what uses the pixel structure of drawing 2. However, this amendment approach is applicable also to the display which used the pixel structure of other arbitration.

[0094] If drawing 2 is referred to, the electrical potential difference saved at Node A will be the gate voltage of N2, therefore the current which passes along N2 and LED will be decided. An LED current can be changed by changing the electrical potential difference on N2. The relation between the gate voltage on N2 and the current which passes along LED is taken into consideration. Gate voltage Vg can be divided into two of the electrical potential differences Vdiode which cross the gate pair source electrical potential differences Vgs and LED of N2 like the following formulas (2).

[0095]

[Equation 2]

$$V_g = V_{gs} + V_{diode} \quad (2)$$

[0096] The drain current of the MOS transistor of a saturation state is expressed with the following formulas (3).

[0097]

[Equation 3]

$$I = \frac{2}{k} (V_{gs} - V_t)^2 \quad (3)$$

[0098] Here, k is the mutual-conductance parameter of a device and Vt is threshold voltage (the actuation in the Rhine form field is referring to the following). Therefore, the following formulas (4) are obtained.

[0099]

[Equation 4]

$$V_{gs} = \sqrt{\frac{2I}{k}} + V_t \quad (4)$$

[0100] The positive current which passes along OLED is expressed with the following formulas (5).

[0101]

[Equation 5]

$$I = AV_{diode}^m \quad (5)$$

[0102] Here, A and m are constants (Burrows other J.Appl.Phys.79 (1996) reference). Therefore, the following formulas (6) are obtained.

[0103]

[Equation 6]

$$V_{diode} = \sqrt[m]{\frac{I}{A}} \quad (6)$$

[0104] Therefore, the overall relation between gate current and a diode current is expressed with the following formulas (7).

[0105]

[Equation 7]

$$V_g = V_t + \sqrt{\frac{2I}{k}} + \sqrt[m]{\frac{I}{A}} \quad (7)$$

[0106] Although other functional forms can also be used since the I-V property of OLED is expressed, according to the above-mentioned formula, it should note bringing about the functional relation from which it differs between gate current and a diode current. However, this invention can be fitted so that it may not be limited to a function form with the detailed I-V property of above OLED, therefore may operate about the diode-property of arbitration.

[0107] The brightness L of OLED is proportional to the current I mostly, and a proportionality constant's is stable and uniform over the whole display surface. If the OLED current decided good can be generated, a display will serve as homogeneity visually. However, as explained above, the pixel is programmed not using the current I but using the electrical potential difference Vg. The problem is the point that the parameters Vt and k of TFT other than the parameters A and m of OLED cross all over a display, and present a certain amount of initial heterogeneity. Furthermore, it is common knowledge that Vt increases under bias temperature stress conditions. It is known that the OLED parameter A will decrease under bias stress directly in relation to the turn-on electrical potential difference of OLED. The OLED parameter m has relation in distribution of the trap in an organic band gap, and changes over all the lives of OLED. Therefore, it is expected that these parameters are uneven in early stages, and it changes over all the lives of a display depending on each bias hysteresis of each pixel. If gate voltage is programmed without amending fluctuation of these parameters, a display will be uneven in early stages and heterogeneity will increase over all the lives.

[0108] There is actually another cause of heterogeneity. Gate voltage Vg is not necessarily equal to the meant data electrical potential difference Vdata. The gain error in a data driver, an offset error, and the feed through (data dependency) generated from selection discharge of N1 make these two electrical potential differences produce a difference rather. These causes of an error are also uneven, and it changes over all the lives of a display. The above, and other gain errors and offset errors are expressed with the following formulas (8).

[0109]

[Equation 8]

$$V_g = BV_{data} + V_0 \quad (8)$$

[0110] Here, B and V0 are a gain factor and offset voltage, respectively, both, are uneven and are obtained. If it arranges combining a formula (7) and (8), the following formulas (9) will be obtained.

[0111]

[Equation 9]

$$V_{data} = V_{off} + C\sqrt{I} + D\sqrt[m]{I} \quad (9)$$

[0112] Here, Voff, and C and D are the above-mentioned parameter combination.

[0113] Since this invention amends fluctuation of Voff, and C, D and m, it offers the various amendment approaches which amend the data (input) electrical potential difference to mean, and enables generating of the OLED current in a pixel array decided good by it. Since fluctuation of Parameter Voff, and C, D and m is amended, the above-mentioned external current detecting circuit can measure from the outside the current pulled out by the information about each pixel, i.e., a single pixel. The information measured about Parameter Voff, and C, D and m is used, and during the usual display actuation, this invention calculates the suitable data electrical potential difference Vdata according to a formula (9) in order to decide a required OLED current.

[0114] Moreover, it becomes expensive by computer to calculate correctly four parameters Voff, and C, D and m from the measured value of a current, and complicated repeat count is needed. However, the good approximation which reduces the complexity of count can be used, maintaining effective amendment.

[0115] In a desirable embodiment, the ununiformity property of a pixel can be expressed as mentioned above using only two parameters instead of four pieces. When the current potential property of the pixel of a formula (9) is referred to, in the usual lighting level, the CrootI term about Vgs of N2 and the DmrootI term about Vdiode are the almost same magnitude. However, the dependencies to those pixel currents differ greatly. Since the value of m is about 10, in ordinary lighting level, DmrootI is the function of far weak I as compared with CrootI. For example, if I is made to increase by 100 times, CrootI will increase 10 times, but DmrootI will not increase 1.58 times (if m is assumed to be 10). That is, in ordinary lighting current level, the I-V curve of OLED serves as a steep slope from the I-Vgs curve of TFT far.

[0116] Therefore, in ordinary current level, DmrootI is independent to a current and approximation [ fluctuation / for every pixel of the ] that it can only process as one offset error is performed. Although this approximation carries in some errors, the appearance of the whole display does not deteriorate sharply. Therefore, the heterogeneity of all displays can be processed as fluctuation of offset and gain in a remarkable precision. Therefore, (9) types can be approximated like the following formulas (10).

[0117]

[Equation 10]

$$V_{data} = V_{offset} + C\sqrt{I} \quad (10)$$

[0118] Here, it is Voffset. = Voff + DmrootI changes Voffset and C for every pixel including DmrootI.

[0119] **Drawing 14** is the flow chart of the approach 1400 of initializing a display by measurement of the parameter of all pixels. An approach 1400 begins from step 1405, and progresses to step 1410, and an "off-" data electrical potential difference is impressed to all pixels other than the pixel made into the object within a pixel block there.

[0120] In step 1420, in order to calculate target specific Voffset and specific C of a pixel, an approach 1400 impresses two data electrical potential differences (V1 and V2), and measures a current about each data electrical potential difference.

[0121] In step 1430, the square root of currents I1 and I2 is calculated. In a desirable embodiment, a square root table is used for this count.

[0122] Voffset and C are calculated in step 1440. That is, two formulas can be used for asking for two variables. Next, Voffset and C which were asked for the specific object pixel are saved at storage, for example, memory. If measurement of all pixels finishes, memory saves two parameters Voffset and C about each pixel in an array. These values are behind applicable to the calibration of Vdata, or adjustment using a formula (10). An approach 1400 is ended in step 1455 next.

[0123] The current which passes along the pixel measured should note fully having to be high so that DmrootI may become almost equal in two point of measurement. As for this condition, it is desirable that it may be made satisfied by performing one measurement in the highest data electrical potential difference which a system can generate, and then performing measurement of another side in a slightly low data electrical potential difference.

[0124] If initialization of a display is performed, the raw input video data supplied to the display module is correctable. The input video data should note being able to exist in various formats, such as for example, (1) pixel electrical potential difference, pixel brightness by which (2) gamma corrections were carried out, or (3) pixel current. Therefore, it depends on each specific format for use of the parameters Voffset and C with

which it was saved for performing the calibration of an input video data, or amendment.

[0125] Drawing 15 is the flow chart of the correction approach 1500 of the input video data showing a pixel electrical potential difference. An approach 1500 begins from step 1505, and progresses to step 1510, and the parameter saved about the object pixel there, for example, Voffset and C, is taken out.

[0126] In step 1520, an approach 1500 impresses the taken-out parameter in order to perform the calibration of an input video data. Bias has not started an input video data, i.e., more specifically, it is expected that a zero bolt expresses zero brightness and larger data than zero express a larger intensity level than zero. Therefore, it can be considered that an electrical potential difference is equal to  $C0 \text{ root}I$ . Here, I is [ the constant of a need current and C0, for example, a typical value, ]  $103V/\text{root}A$ . In order to amend the pixel fluctuation at the time of an input video data going into a display module, it is Voffset about each pixel.  $= Voff + C\text{root}I$  is calculated based on Voffset and C which were saved. This count consists of hanging  $C/C0$  on a video data, and adding Voffset to that result. The division by C0 is unnecessary if the video data Vdata is already reduced by fixed multiplier  $1 / C0$  fixed. Multiplication by C can be performed by digital logic using direct or a look-up table. For example, in the case of the latter, each value of C specifies the table whose table entry is as a result of multiplication while the value of a video data is an index. (Or the input video data in a look-up table and the role of C can also be made reverse.) After multiplication is performed, rapid addition of Voffset is performed by digital logic.

[0127] In step 1530, the obtained electrical potential difference Vdata, i.e., the input data corrected or adjusted, is sent to the data driver of a pixel array. An approach 1500 is ended at step 1535 next.

[0128] In the case of the brightness data by which the gamma correction was carried out, an input video data is proportional to  $L0.45$ . Here, L is brightness. This is typical in the video data beforehand amended about the CRT brightness-voltage characteristic. It is  $L0.45=\text{root}L$ , and since OLED brightness is proportional to the current, data can be processed as a thing proportional to  $\text{root}I$ . Therefore, count can be performed by the approach about the zero offset electrical potential difference explained previously, and the same approach.

[0129] Drawing 16 is the flow chart of the amendment approach 1600 of the input video data showing a pixel current, i.e., brightness. An approach 1600 begins from step 1605, and progresses to step 1610, and the value of the square root of the current measured there is calculated. That is, the approach 1600 is the same as the above-mentioned approach 1500 except being processed so that the video data showing I may generate  $\text{root}I$ . As mentioned above, this operation can be performed from a pixel amperometry value using the table which gives the value of a square root required to ask for the pixel parameters Voffset and C, as shown in drawing 14.  $\text{root}I$  is again generated from a video data here using this table.

[0130] Next, the data correction step 1610 thru/or 1645 are the same as that of the above-mentioned approach 1500 except asking for the data electrical potential difference which hung C on the input data in step 1630, then added Voffset, and was amended.

[0131] Or in another embodiment, the ununiformity property of a pixel can be expressed as mentioned above not using two pieces or four parameters but using one parameter. That is, as the ununiformity property of a pixel is expressed using a single parameter, it is simplified further.

[0132] Furthermore, in many cases, fluctuation of gain factor C for every pixel is small, and, specifically, only Voffset remains as a significant cause of heterogeneity. This is generated when the TFT mutual-conductance parameter k and electrical-potential-difference gain factor B are homogeneity. In this case, it is enough if only Voffset of each pixel is calculated. If it does so, data correction will not perform multiplication (since it is considered that a gain factor is uniform), but will perform only addition of an offset parameter.

[0133] This single parameter technique is similar to the above-mentioned auto-zero-ized OLED pixel structure. This single parameter amendment approach should produce the display homogeneity which should be satisfied while reducing computer costs. However, in use of a specific display with very important homogeneous maintenance of a display, even if the complexity and costs of a computer increase, two above-mentioned pieces or the above-mentioned four-piece parameter approach can be used.

[0134] Here, a display initialization process is influenced by format (format) of data about single electrical parameter extraction and data correction. The single parameter technique is applicable to initialization of a display, and amendment of a video data, when a video data expresses (1) pixel electrical potential difference, (2) pixel current, and the pixel brightness by which (3) gamma corrections were carried out.

[0135] Drawing 17 shows the flow chart of the initialization approach of the display by measurement of the parameter of all pixels. An approach 1700 begins from step 1705, and progresses to step 1710, and an "off-" data electrical potential difference is impressed to all pixels other than the object pixel within a pixel block there. In step 1720, in order to calculate target specific Voffset and specific C about a pixel, an approach

1700 impresses the data electrical potential difference (V1 and V2) of two pieces, and measures a current for every data electrical potential difference.

[0136] In step 1730, the square root of currents I1 and I2 is calculated. In a desirable embodiment, a square root table is used for this count.

[0137] Since it is thought that the value of C is uniform, it should note being able to ask for it by performing two-point measurement in the location of the arbitration in a display ideally. However, since this may have the unusual object pixel, it may have a problem. Therefore, two-point measurement is performed for every pixel.

[0138] The average of C is calculated in step 1740. Namely, the average of C of a display can be calculated by using the table for calculating rootI about each amperometry value.

[0139] In step 1750, the average C is used from the amperometry value of each pixel, and Voffset of each pixel is calculated. Thus, small fluctuation of C covering the whole display is partially amended by count of Voffset. It is desirable to measure measurement of the current of each pixel in the possible highest data electrical potential difference for the reason for the above.

[0140] Finally in step 1760, Voffset of each pixel is saved at storage, for example, memory. Next, an approach 1700 is ended in step 1765.

[0141] Drawing 18 is the flow chart of the amendment approach 1800 of the input video data showing a pixel electrical potential difference. An approach 1800 begins from step 1805, progresses to step 1810, and takes out the parameter Voffset saved about the object pixel there.

[0142] In step 1820, an approach 1800 performs the calibration of an input video data using the taken-out parameter Voffset. More specifically based on the value of saved Voffset, it is Vdata about each pixel. = Voffset+Vdata A value is calculated.

[0143] In step 1830, the obtained input data which was Vdata(ed), namely, amended or adjusted is sent to the data driver of a pixel array. Next, an approach 1800 is ended in step 1835.

[0144] Drawing 19 is the flow chart of the initialization approach 1900 of the display by measurement of the parameter of all the pixels about the situation that a video data expresses a pixel current. There is a close resemblance between an approach 1900 and the above-mentioned approach 1700. The difference with the above-mentioned approach 1700 is the case where use the average value of C by which it was calculated by the approach 1900 having taken in additional step 1950, and the table of a zero offset data electrical-potential-difference pair pixel current is created. A square root operation is not performed by using this table in previous initialization and a previous data correction process from this point. This table is a precision higher than a square root function, and it is expected that the current-voltage characteristic of a pixel is expressed. Next, since this table uses it later, it is saved by it at storage, for example, memory. Next, each pixel amperometry value is used as an index for putting into this table, and each pixel offset Voffset is searched for.

[0145] Drawing 20 is the flow chart of the amendment approach 2000 of the input video data showing a pixel current, i.e., brightness. An approach 2000 begins from step 2005, progresses to step 2010, and takes out Voffset of the pixel made into a current object there from storage.

[0146] In step 2020, it asks for a zero offset data electrical potential difference from an input video-data current using the table of a zero offset data electrical-potential-difference pair pixel current. In step 2030, this zero offset data electrical potential difference is applied to taken-out Voffset. Finally, in step 2040, the input video data amended or adjusted is sent to the data driver of a pixel array.

[0147] In short, if a video data is introduced into a display module, the zero offset data electrical potential difference corresponding to each current will be searched in a V-I table. Next, the pixel offset saved is added to zero offset voltage, and the result serves as an input to a data driver. An approach 2000 is ended in step 2045 next.

[0148] Drawing 21 is the flow chart of the initialization approach 2100 of the display by measurement of the parameter of all the pixels about the situation of expressing the brightness data with which the gamma correction of the video data was carried out. There is a close resemblance between an approach 2100 and the above-mentioned approach 1900. The difference with an approach 2100 and the above-mentioned approach 1900 is a time of creating the table of the square root of a zero offset data electrical-potential-difference pair pixel current using the average value of calculated C in step 2150. That is, a video data can be made to approximate as a thing showing rootI. Therefore, the zero-offset table of Vdata pair rootI is created using the average of C, and this table is saved at storage, such as memory.

[0149] Drawing 22 is the flow chart of the amendment approach 2200 of the input video data showing the brightness data by which the gamma correction was carried out. There is a close resemblance between an



approach 2200 and the above-mentioned approach 2000. The difference with the above-mentioned approach 2000 is generated in the zero-offset table of Vdata pair rootI. Therefore, in short, a zero offset data electrical potential difference is looked for using the video data which enters, and the saved pixel offset is added to these electrical potential differences.

[0150] In the above-mentioned explanation, it is regarded as that to which the OLED drive transistor N2 operates by the saturation state. If N2 operates in the Rhine form field, the similar amendment approach can be used. In that case, the current potential property of a pixel is expressed with the following formulas (11).

[0151]

[Equation 11]

$$V_{data} = V_{off} + C(I)I + D \sqrt[m]{I} \quad (11)$$

[0152] Here, C(I) is the weak function of I. Here, as mentioned above, if a current is fully high to extent which should ask only for an offset term and a gain factor, a DmrootI term can be included in it at a Voff term. However, since gain factor C(I) contains the uneven OLED parameters A and m, the single parameter approximation which considers that only offset voltage is an ununiformity is not expected to be as accurate as the single parameter approximation about the case of the above-mentioned saturation. Therefore, if N2 operates in the Rhine form field, the two-piece parameter amendment approach will be considered to be far powerful rather than the single parameter amendment approach.

[0153] Drawing 23 is the block diagram of the system 2300 which used the display 2320 equipped with two or more active-matrix LED pixel structures 300, 500, or 700 of this invention. A system 2300 consists of a display controller 2310 and a display 2320.

[0154] Furthermore, specifically, a display controller can be taken as a central processing unit CPU (2312), memory 2314, and the general purpose computer that has two or more I/O devices (for example, various modules, such as stores, such as a mouse, a keyboard, a magnetic device, and optical equipment, a modem, an A/D converter, and the above-mentioned measurement module 1330). The software instruction (for example, the above-mentioned various approaches) for operating a display 2320 can be loaded to memory 2314 from a storage, and can be executed by CPU2312. Therefore, the software instruction of this invention can be saved to the medium which can be read by computer.

[0155] A display 2320 consists of the pixel interface 2322 and two or more pixels (pixel structures 300, 500, or 700). The pixel interface 2322 includes a circuit required for the drive of pixels 300, 500, or 700. For example, the pixel interface 2322 can be considered as a matrix addressing interface as shown in drawing 1, and can include the additional above-mentioned signal line/control line as an option.

[0156] Therefore, a system 2300 can be carried out as a laptop computer. Or a display controller 2310 can carry out as a microcontroller or the integrated circuit (ASIC) of a specified use, or combination of hardware and a software instruction. In short, a system 2300 can be carried out in the big system incorporating this invention.

[0157] Although this invention was explained as what uses an NMOS transistor, this invention is realizable even if it uses the PMOS transistor which the related electrical potential difference reversed.

[0158] As mentioned above, although the various embodiments of this invention were shown in this specification and explained to the detail, many modes can be taken unless the summary of this invention is exceeded.

[0159]

[Effect of the Invention] The homogeneity of brightness is improved sharply and, as for the display of this invention, the industrial value is high.

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[Translation done.]

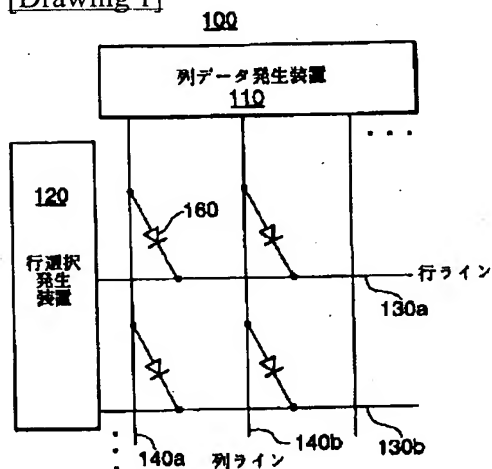
## \* NOTICES \*

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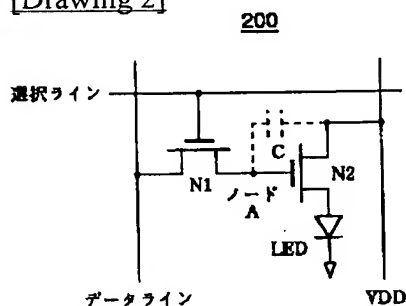
1. This document has been translated by computer. So the translation may not reflect the original precisely.
2. \*\*\*\* shows the word which can not be translated.
3. In the drawings, any words are not translated.

## DRAWINGS

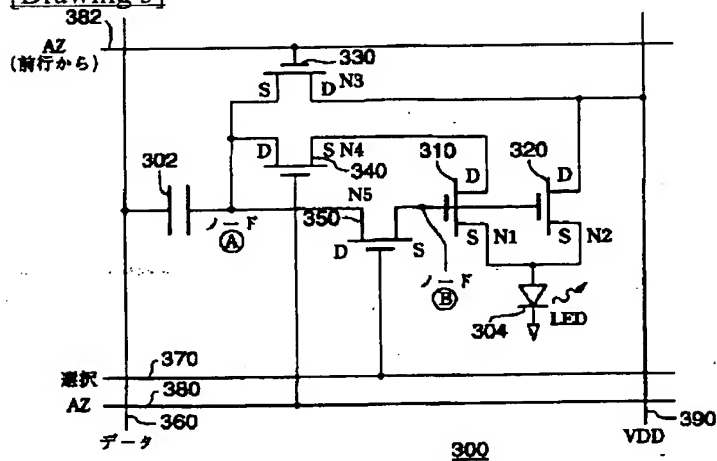
[Drawing 1]



[Drawing 2]

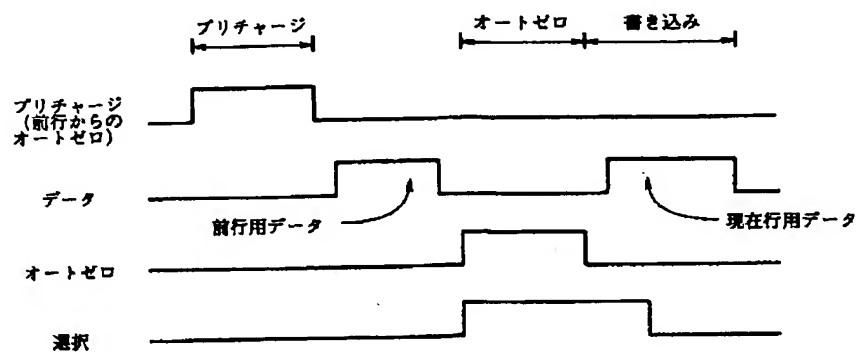


[Drawing 3]

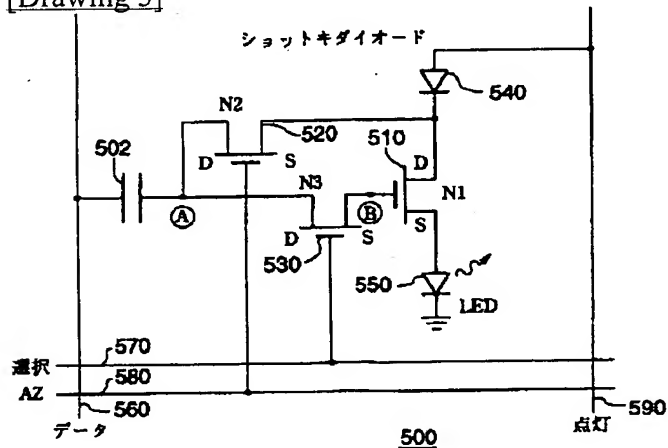


[Drawing 4]

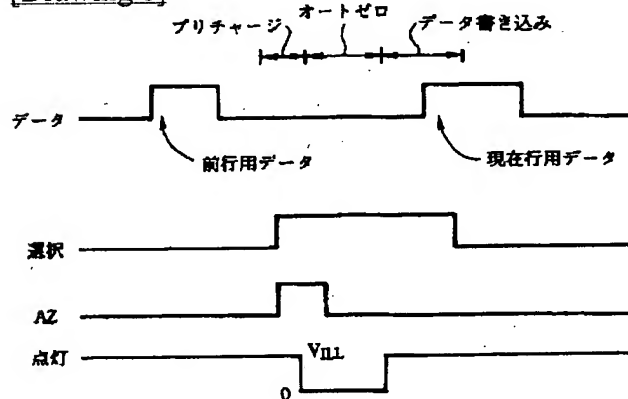




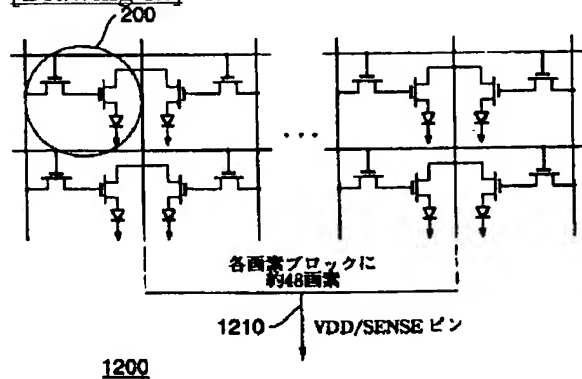
[Drawing 5]



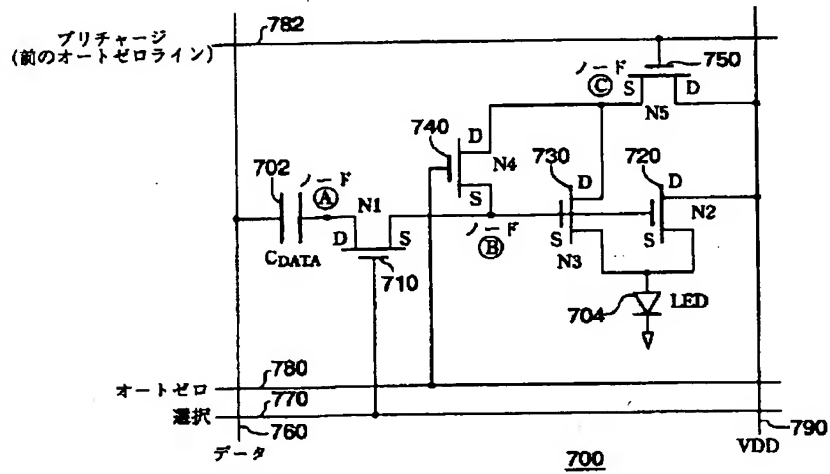
[Drawing 6]



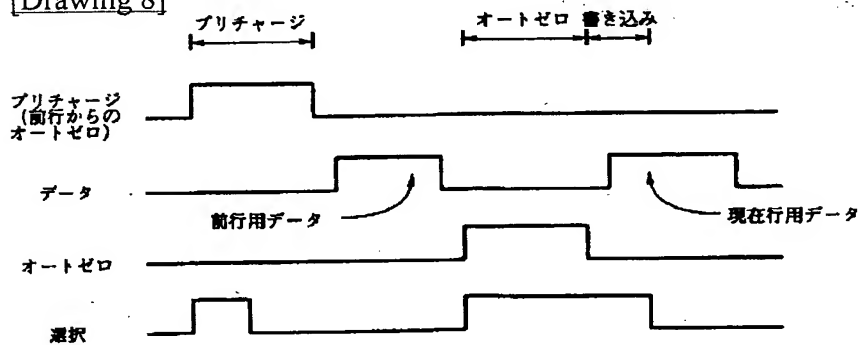
[Drawing 12]



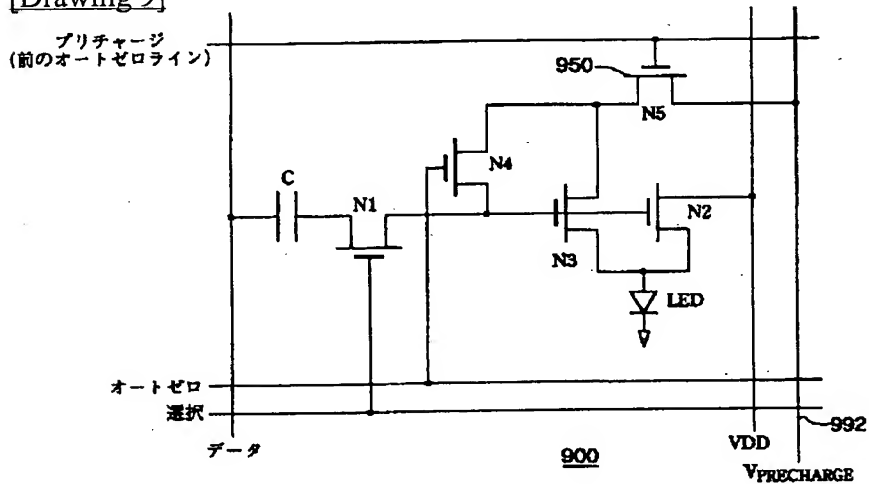
[Drawing 7]



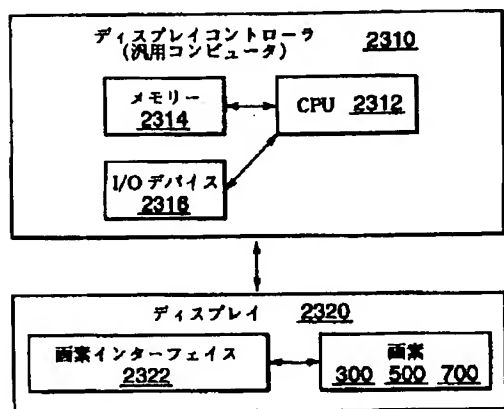
[Drawing 8]



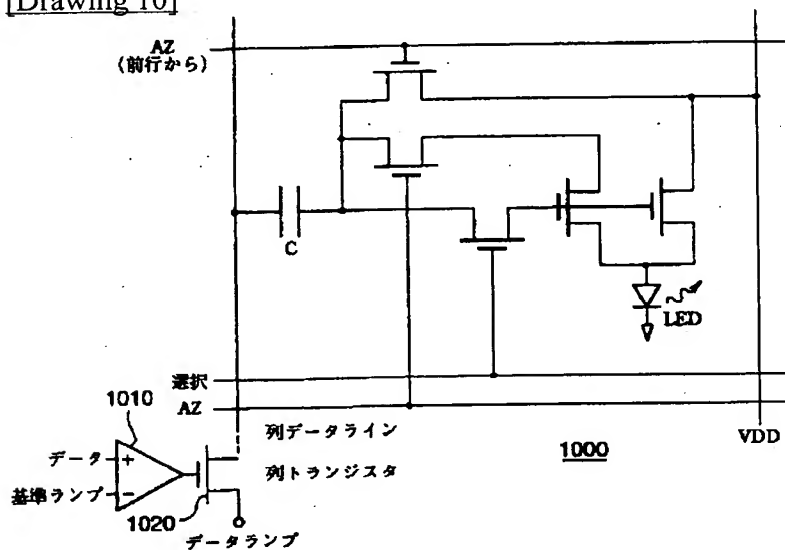
[Drawing 9]



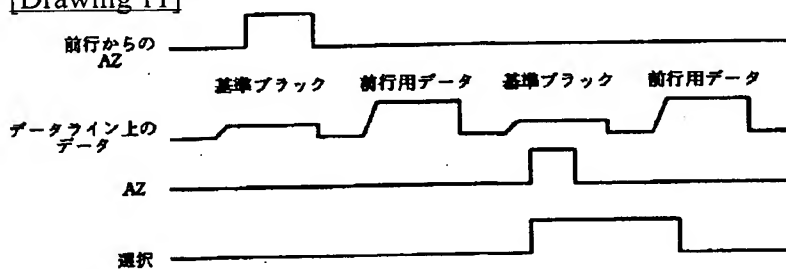
[Drawing 23]



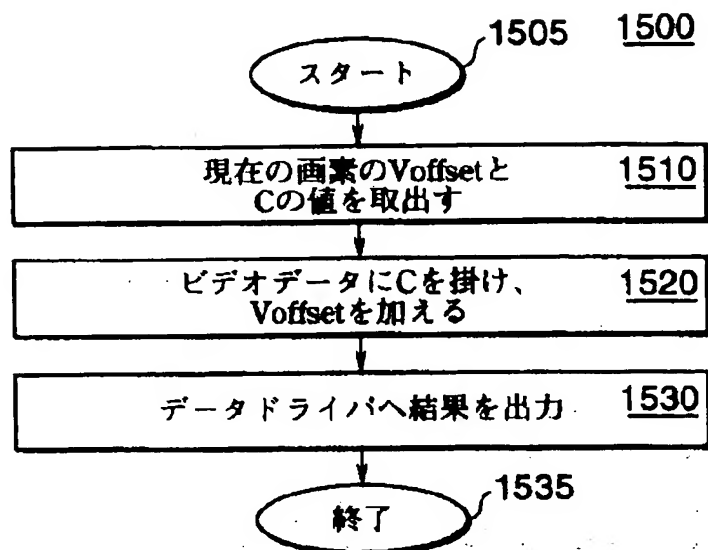
[Drawing 10]



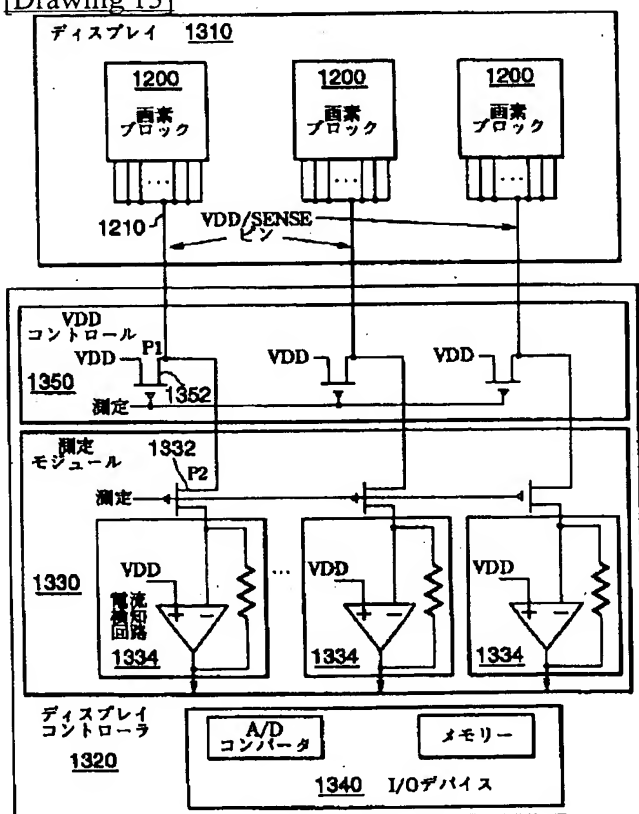
[Drawing 11]



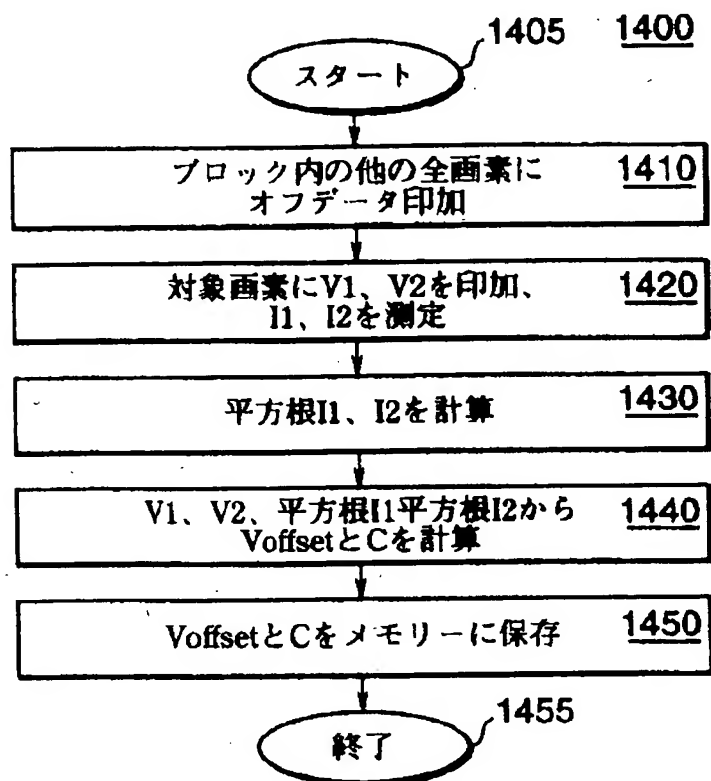
[Drawing 15]



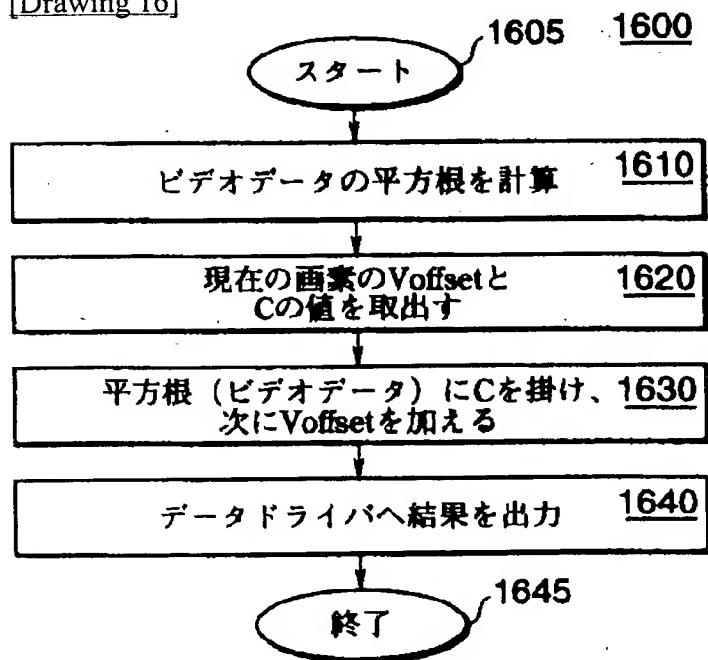
[Drawing 13]



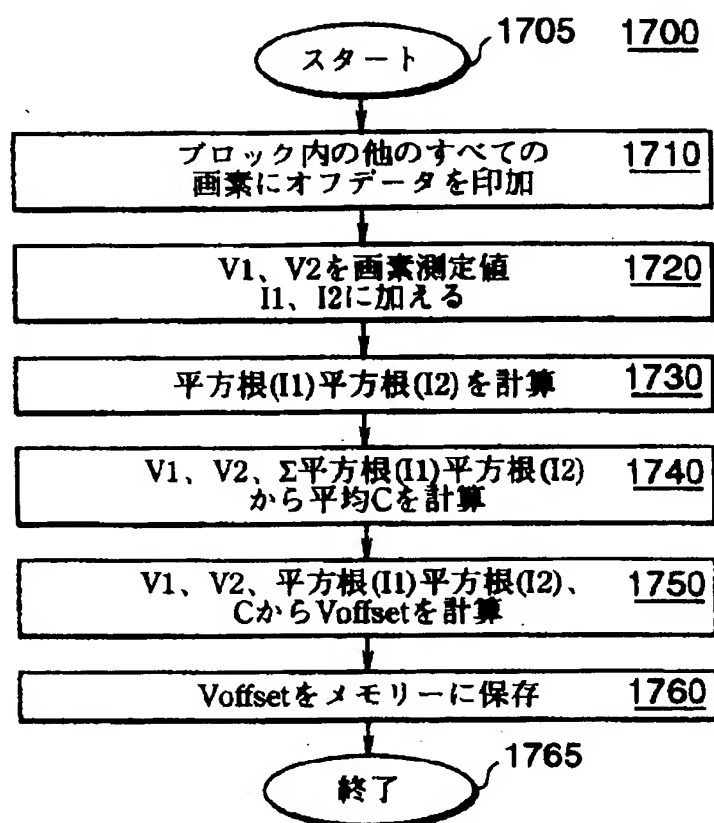
[Drawing 14]



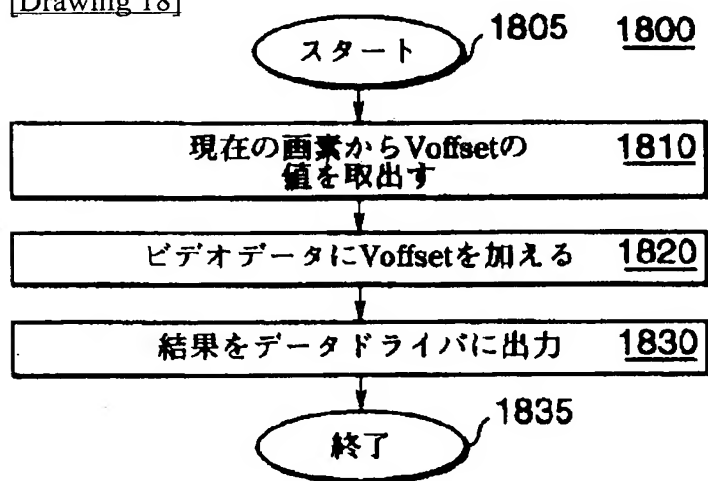
[Drawing 16]



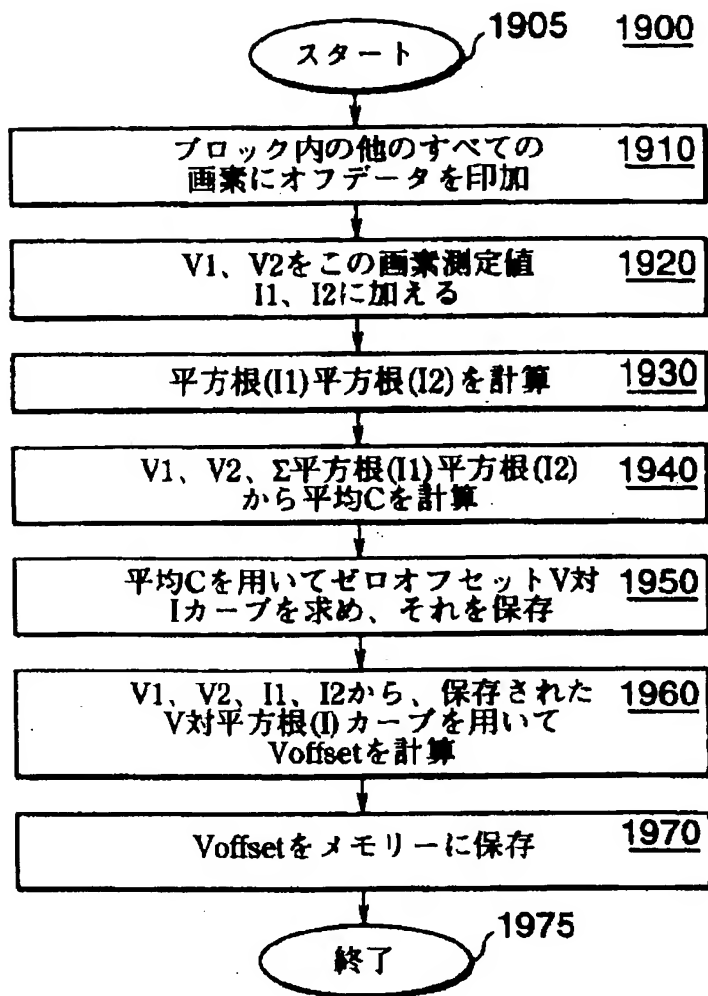
[Drawing 17]



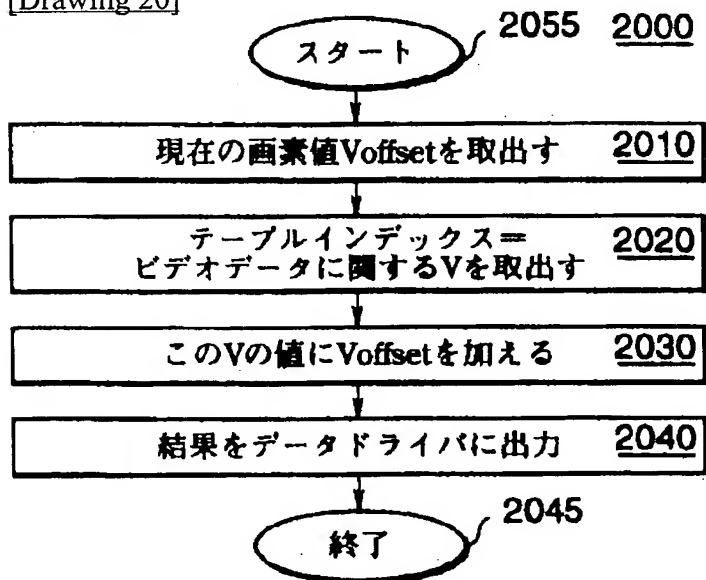
[Drawing 18]



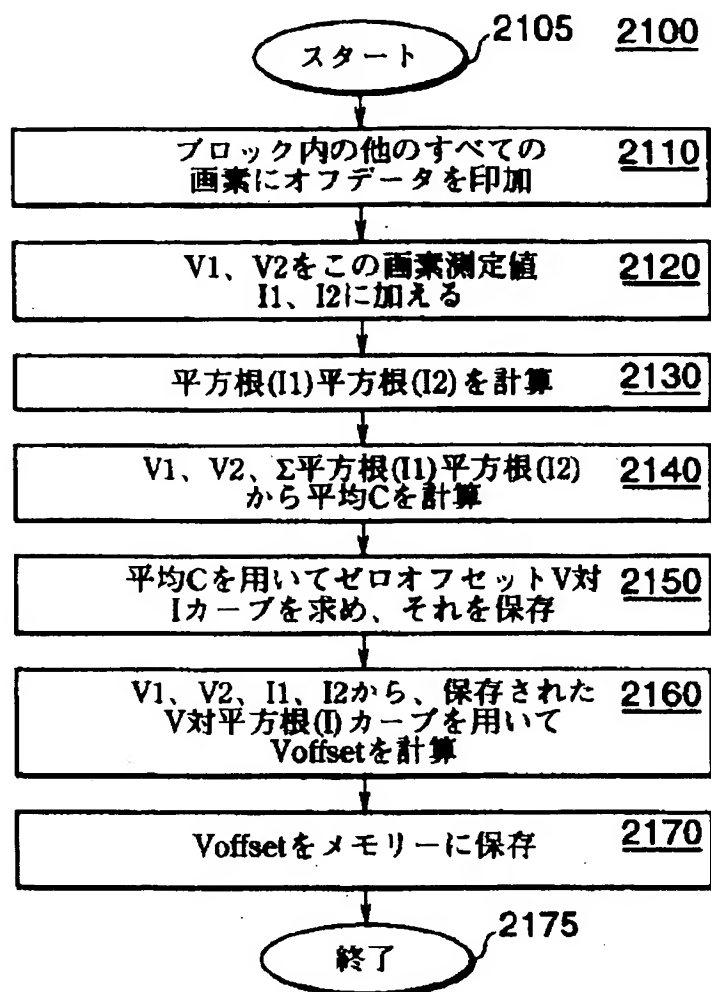
[Drawing 19]



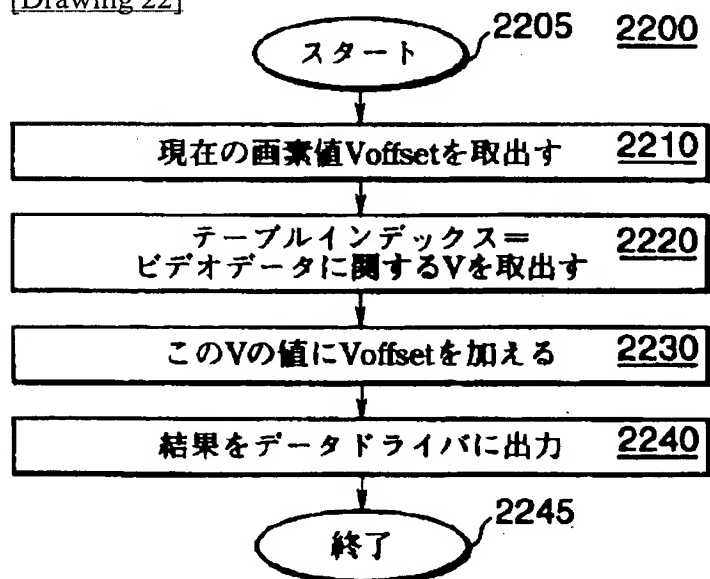
[Drawing 20]



[Drawing 21]



[Drawing 22]



[Translation done.]



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44

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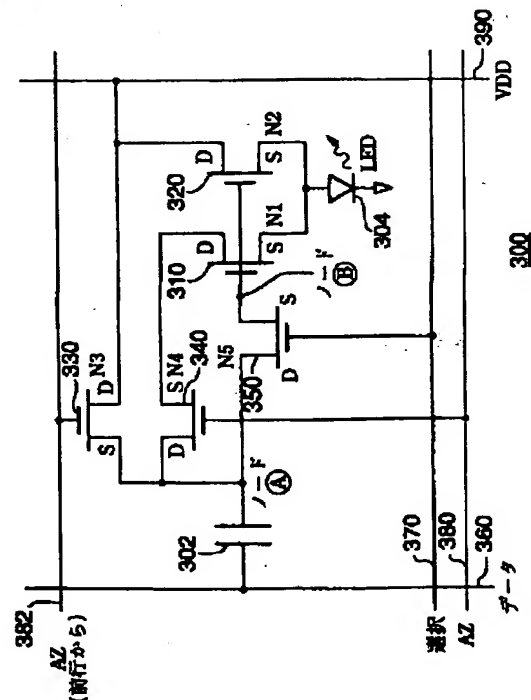
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(54)【発明の名称】 アクティブマトリックス発光ダイオード画素構造およびその方法

(57)【要約】

【課題】画素構造の発光ダイオードにおける電流の不均一性を低減することによって、輝度の不均一性を改善するLED画素構造と方法とを提供する。

【解決手段】少なくとも一つの画素を備えるディスプレイであって、上記画素は、第1トランジスタと、キャパシタと、第2トランジスタと、第3トランジスタと、第4トランジスタと、第5トランジスタと、光要素とから成り、それらの構成要素を特定に接続することにより構成されていることを特徴とするディスプレイ。



## 【特許請求の範囲】

【請求項1】 少なくとも一つの画素を備えるディスプレイであって、当該画素は、(1)第1選択ラインへの接続用であるゲートと、ソースと、ドレインとを有する第1トランジスタと、(2)当該第1トランジスタのドレインが接続されている第1端子と、第2端子とを有するキャパシタと(3)オートゼロラインへの接続用であるゲートと、ソースと、当該第1トランジスタの当該ドレインが接続されているドレインとを有する第2トランジスタと、(4)第2選択ラインへの接続用であるゲートと、当該第2トランジスタのドレインに接続されたソースと、ドレインとを有する第3トランジスタと、

(5)当該第1トランジスタのソースに接続されたゲートと、ソースと、当該第2トランジスタの当該ソースに接続されたドレインとを有する第4トランジスタと、

(6)当該第1トランジスタのソースに接続されたゲートと、ソースと、当該第3トランジスタの当該ドレインに接続されたドレインとを有する第5トランジスタと、

(7)当該第4トランジスタのソースと当該第5トランジスタのソースとが、一方の端子に接続されている2個の端子を有する光要素とから成ることを特徴とするディスプレイ。

【請求項2】 前記光要素が有機発光ダイオード(OLED)である請求項1に記載のディスプレイ。

【請求項3】 前記各トランジスタが非晶質シリコンから造られた薄膜トランジスタである請求項1又は2に記載のディスプレイ。

【請求項4】 前記第2選択ラインが前行からのオートゼロラインである請求項1～3の何れかに記載のディスプレイ。

【請求項5】 少なくとも一つの画素を備えたディスプレイであって、当該画素は、(1)一つの選択ラインへの接続用であるゲートと、ソースと、ドレインとを有する第1トランジスタと、(2)当該第1トランジスタのドレインが接続されている第1端子と、第2端子とを有するキャパシタと、(3)オートゼロラインへの接続用であるゲートと、ソースと、当該第1トランジスタの当該ドレインが接続されているドレインとを有する第2トランジスタと、(4)当該第2トランジスタのソースに接続された第1端子と、点灯ラインへの接続用の第2端子とを有するダイオードと、(5)第1トランジスタのソースに接続されたゲートと、ソースと、当該ダイオードの第1端子に接続されたドレインとを有する第3トランジスタと、(6)当該第3トランジスタのソースが、一方の端子に接続されている2個の端子を有する光要素とから成ることを特徴とするディスプレイ。

【請求項6】 前記ダイオードがショットキダイオードである請求項5に記載のディスプレイ。

【請求項7】 少なくとも一つの画素を備えたディスプレイであって、当該画素は、(1)第1選択ラインへの

接続用であるゲートと、ソースと、ドレインとを有する第1トランジスタと、(2)当該第1トランジスタのドレインが接続されている第1端子と、第2端子とを有するキャパシタと、(3)オートゼロラインへの接続用であるゲートと、当該第1トランジスタの当該ソースが接続されているソースと、ドレインとを有する第2トランジスタと、(4)第2選択ラインへの接続用であるゲートと、当該第2トランジスタのドレインに接続されたソースと、ドレインとを有する第3トランジスタと、

(5)当該第1トランジスタのソースに接続されたゲートと、ソースと、当該第3トランジスタの上記ソースに接続されたドレインとを有する第4トランジスタと、

(6)当該第1トランジスタのソースに接続されたゲートと、ソースと、当該第3トランジスタの当該ドレインに接続されたドレインとを有する第5トランジスタと、

(7)当該第4トランジスタのソースと当該第5トランジスタのソースとが、一方の端子に接続されている2個の端子を有する光要素とから成ることを特徴とするディスプレイ。

【請求項8】 前記光要素が有機発光ダイオード(OLED)である請求項7に記載のディスプレイ。

【請求項9】 前記第2選択ラインが前行からのオートゼロラインである請求項7又は8に記載のディスプレイ。

【請求項10】 (1)少なくとも一つのオートゼロ化画素構造と、(2)当該オートゼロ化画素構造にオートゼロ化の実行を可能にするため、当該オートゼロ化画素構造に接続されたオートゼロラインと、(3)オートゼロ電圧の範囲を拡張するため、一つの電圧を当該オートゼロ化画素構造に運ぶように、当該オートゼロ化画素構造に接続された第2ラインとから成るディスプレイ。

【請求項11】 光要素への印加エネルギーを制御する回路を含む少なくとも1個の画素を有するディスプレイを点灯する方法であって、(a)画素をオートゼロ化するステップと、(b)データライン経由でデータを当該画素へロードするステップと、(c)保存されたデータに基づいて当該光要素を点灯するステップとから成ることを特徴とする方法。

【請求項12】 前記オートゼロ化ステップ(a)の前に前記画素をプリチャージするステップを更に含む請求項11に記載の方法。

【請求項13】 前記オートゼロ化ステップ(a)が基準ブラックレベルを印加するステップを含む請求項11又は12に記載の方法。

【請求項14】 少なくとも1個の画素を有するディスプレイを点灯する方法であって、(a)当該画素の画素パラメータを測定するステップと、(b)測定された画素パラメータに基づいて入力画素データを調整するステップと、(c)調整された入力画素データに基づいて当該画素を点灯するステップとから成ることを特徴とする

方法。

【請求項15】 前記測定ステップ(a)が前記画素によって引き出された電流を外部的に測定する請求項14に記載の方法。

【請求項16】 前記調整ステップ(b)が、電圧オフセット( $V_{offset}$ )パラメータを求めるため、前記測定された画素パラメータを使用して前記画素データを補正する請求項14又は15に記載の方法。

【請求項17】 前記調整ステップ(b)が、更に、ゲイン係数(C)パラメータを求めるため、前記測定された画素パラメータを使用して前記画素データを補正する請求項16に記載の方法。

【請求項18】 ディスプレイコントローラと当該ディスプレイコントローラに接続されると共に複数の画素から成るディスプレイとから成るシステムであって、当該各画素が、(1)第1選択ラインへの接続用ゲートと、ソースと、およびドレインとから成る第1トランジスタと、(2)当該第1トランジスタの当該ドレインに接続された第1端子と、第2端子とを有するキャパシタと、(3)オートゼロラインへの接続用ゲートと、当該第1トランジスタの当該ソースに接続されたソースと、ドレインとを有する第2トランジスタと、(4)第2選択ラインへの接続用ゲートと、当該第2トランジスタの当該ドレインに接続されたソースと、ドレインとを有する第3トランジスタと、(5)当該第1トランジスタの当該ソースに接続されたゲートと、ソースと、当該第3トランジスタの当該ソースに接続されたドレインとを有する第4トランジスタと、(6)当該第1トランジスタの当該ソースに接続されたゲートと、ソースと、当該第3トランジスタの当該ドレインに接続されたドレインとを有する第5トランジスタと、(7)当該第4トランジスタのソースと当該第5トランジスタのソースとが、一方の端子に接続されている2個の端子を有する光要素とから成ることを特徴とするシステム。

【請求項19】 (1)画素の画素パラメータを測定するための測定モジュールと、(2)当該測定された画素パラメータを保存するための記憶装置とを有するディスプレイコントローラと、(3)当該保存された画素パラメータに基づいて調整された入力画素データを表示するため、当該ディスプレイコントローラに接続されたディスプレイとから成るシステム。

【請求項20】 前記測定モジュールが前記画素によって引き出される電流を測定するための電流検知回路を有する請求項19に記載のシステム。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、アクティブマトリックス発光ダイオード画素(ピクセル)構造に関する。本発明は、詳しくは、画素構造の発光ダイオードにおいて電流の不均一性を低減して輝度の均一性を改善する画

素構造と、前記アクティブマトリックス発光ダイオード画素構造の作動方法に関する。尚、本出願は1997年9月29日出願の米国仮出願第60/060,386号および1997年9月29日出願の米国仮出願第60/060,387号の優先権を主張すると共に、本出願に引用する。

【0002】

【従来の技術】図1に示すようなマトリックスアドレッシングを使用して画素を点灯するマトリックスディスプレイは、当該技術分野において周知である。典型的なディスプレイ100は、行と列に構成された画面要素すなわち表示要素(ピクセル)160を有する。このディスプレイは、列データ発生装置110と行データ発生装置120を内蔵している。作動にあたっては、各行は行ライン130を介して順次通電されるとともに、対応する列ラインを使用して対応する画素が通電される。パッシブマトリックスディスプレイにおいては、各行の画素は順次1個ずつ点灯されるが、アクティブマトリックスディスプレイにおいては、各列の画素に順次データがロードされる。すなわち、パッシブマトリックスディスプレイの各列は全フレーム時間のほんの一部分で「通電状態である」に過ぎないが、アクティブマトリックスディスプレイの各列はフレーム時間の全体にわたって「通電状態とする」ことが出来る。

【0003】ポータブルディスプレイ、例えばラップトップコンピュータの普及にともなって、さまざまなプレイ技術、例えば液晶ディスプレイ(LCD)および発光ダイオードディスプレイ(LED)が使用されるようになった。一般的に、ポータブルディスプレイにおいては、ディスプレイを使用するポータブルシステムの電力を節約し、それによってポータブルシステムの「使用時間」を延長できる様にすることが重要である。

【0004】LCDにおいては、ディスプレイの使用中の全期間にわたってバックライトがオンになっている。すなわち、LCD内のすべての画素が点灯され、ある画素を「暗く」するには、画素を通る光を偏光層でさえぎる。これに対して、LEDディスプレイは、通電された画素のみが点灯され、暗い画素を点灯する必要をなくして省電力を図っている。

【0005】図2に、2個のNMOSトランジスタN1とN2を有する従来技術のアクティブマトリックスLED画素構造200を示す。この画素構造においては、トランジスタN1に通電することによりコンデンサCにデータ(電圧)が先ず保存され、次に「駆動トランジスタ」N2に通電してLEDを点灯する。画素構造200を使用したディスプレイでも節電は可能であるが、この画素構造では、いくつかの原因により不均一な輝度レベルを呈する。

【0006】第一に、LEDの輝度はそこを通る電流に比例することが観測されている。使用中、「駆動トランジスタ」N2の閾値電圧がドリフトするためLEDを通

る電流が変化する可能性がある。この電流の変化がディスプレイの輝度の不均一性の一因となる。

【0007】第二に、ディスプレイの輝度の不均一性のもう一つの原因は、「駆動トランジスタ」N2の製造において見いだすことが出来る。いくつかの場合に、「駆動トランジスタ」N2は、トランジスタの初期閾値電圧の均一性の確保が困難な材料で作られ、その結果、画素ごとに変動する。

【0008】第三に、LEDの電気的パラメータも不均一性を呈することがある。例えば、バイアス温度ストレス条件下では、OLED（有機発光ダイオード）のターンオン電圧の増加が予想される。

【0009】従って、画素構造の「駆動トランジスタ」における閾値電圧の変動に起因する電流の不均一性を低減する画素構造と、それに関連する方法が当該技術分野において必要となっている。

【0010】

【発明が解決しようとする課題】本発明は、画素構造の発光ダイオードにおける電流の不均一性の低減によって輝度の均一性を改善するLED（またはOLED）画素構造と方法を提供することを目的とする。

【0011】

【課題を解決するための手段】上記課題を解決するために、本発明者らは鋭意検討した結果、5個のNMOSTランジスタ、コンデンサ、およびLEDから成る画素構造が上記課題を解決できることを見出し、本発明を完成するに至った。

【0012】すなわち、本発明の第一の要旨は、少なくとも一つの画素を備えるディスプレイであって、当該画素は、（1）第1選択ラインへの接続用であるゲートと、ソースと、ドレインとを有する第1トランジスタと、（2）当該第1トランジスタのドレインが接続されている第1端子と、第2端子とを有するキャパシタと

（3）オートゼロラインへの接続用であるゲートと、ソースと、当該第1トランジスタの当該ドレインが接続されているドレインとを有する第2トランジスタと、

（4）第2選択ラインへの接続用であるゲートと、当該第2トランジスタのドレインに接続されたソースと、ドレインとを有する第3トランジスタと、（5）当該第1トランジスタのソースに接続されたゲートと、ソースと、当該第2トランジスタの当該ソースに接続されたドレインとを有する第4トランジスタと、（6）当該第1トランジスタのソースに接続されたゲートと、ソースと、当該第3トランジスタの当該ドレインに接続されたドレインとを有する第5トランジスタと、（7）当該第4トランジスタのソースと当該第5トランジスタのソースとが、一方の端子に接続されている2個の端子を有する光要素とから成ることを特徴とするディスプレイに存する。

【0013】第1の要旨の好ましい態様において、画素

構造は3個のトランジスタと1個のダイオードから成る。

【0014】第1の要旨の他の好ましい態様において、画素構造は5個のトランジスタを有する異なる画素構造である。

【0015】第1の要旨の他の好ましい態様において、画素構造はオートゼロ化電圧範囲を拡張する追加のラインを1本備える。

【0016】本発明の第2の要旨は、画素パラメータを測定し、それを使用して入力画素データを調節する、一つの外部測定モジュールと種々の測定方法に存する。

【0017】

【発明の実施の形態】以下、本発明を図面を使用して詳しく説明する。尚、理解を容易にするため、各図に共通の要素は可能な限り同一の符号を付した。

【0018】図3は、本発明によるアクティブマトリックスLED画素構造300の略図である。好ましい実施態様において、アクティブマトリックスLED画素構造は、薄膜トランジスタ（TFT）、すなわちポリシリコンまたはアモルファスシリコンを使用して作られたトランジスタを使用して実施される。同様に、好ましい実施態様において、アクティブマトリックスLED画素構造は、有機発光ダイオード（OLED）を使用する。この画素構造は薄膜トランジスタと有機発光ダイオードを使用して実施しているが、本発明は他のタイプのトランジスタや発光ダイオードを使用しても実施できる。

【0019】この画素構造300は、トランジスタ閾値電圧（ $V_t$ ）の不均一性が大きくかつOLEDターンオン電圧の不均一性が大きい場合でも、均一な電流駆動を提供する。すなわち、OLEDを通る電流を均一に保ち、それによってディスプレイの輝度の均一性を確保することが望ましい。

【0020】図3を参照すると、画素構造300は、5個のNMOSTランジスタN1（310）、N2（320）、N3（330）、N4（340）およびN5（350）、コンデンサ302、およびLED（OLED）（光要素）304（光要素）から成る。選択ライン370はトランジスタ350のゲートに接続されている。データライン360はコンデンサ302の一方の端子に接続されている。オートゼロライン380はトランジスタ340のゲートに接続されている。VDDライン390がトランジスタ320、330のドレインに接続されている。画素アレイ内の前の行からのオートゼロライン382が、トランジスタ330のゲートに接続されている。

【0021】前行からのオートゼロライン382は第2の選択ラインとして実施可能であることに注目すべきである。すなわち、現在の画素のタイミングは、前行からのオートゼロライン382が第2の選択ラインを必要とせず利用でき、それによって現在の画素の複雑さとコ

ストを低減するようになっている。

【0022】コンデンサ302の一つの端子は（ノードAにおいて）トランジスタ330のソースと、トランジスタ340、350のドレインに接続されている。トランジスタ350のソースは（ノードBにおいて）トランジスタ310と320のゲートに接続されている。トランジスタ310のドレインはトランジスタ340のソースに接続されている。最後に、トランジスタ310と320のソースはLED304の一方の端子に接続されている。

【0023】前述のように、有機LEDディスプレイの駆動には種々の不均一性による問題が多い。本発明は、これらの問題を対象とする有機LEDディスプレイの構造に関する。すなわち、各LED画素は、LEDターンオン電圧の変動やTFT閾値電圧の変動に鈍感な方法で駆動される。すなわち、現在の画素は、LEDターンオン電圧やTFT閾値電圧の変動に対処するために使用されるオートゼロ化方法を使用して、オフセット電圧パラメータを求めることが出来る。

【0024】更に、従来のアクティブマトリックス液晶ディスプレイにおいて使用された方法に極めて類似する方法によって、各画素にデータがデータ電圧として供給される。その結果、本発明のディスプレイ構造は、従来の行と列のスクヤナに対し、外付けでも内蔵でも使用することが出来る。

【0025】本発明の画素は、5個のTFTと、1個のコンデンサと、LEDとを使用する。TFTの接続は、LEDのカソードにではなく、アノードに接続されることに注目すべきであり、このことは従来の有機LEDにおいてはITOがホールエミッタであるという事実によって必要とされる。従って、LEDはTFTのドレインにではなく、ソースに接続される。各ディスプレイの列は、2本の行ライン（オートゼロラインと選択ライン）と、1-1/2列ライン（データラインと、隣の列と共有する+VDDライン）を有する。各ライン上の波形も図4に示す。画素300の作動を以下3フェーズ、すなわち3段階で詳述する。

【0026】第一フェーズはプリチャージフェーズである。前行382のオートゼロ（AZ）ライン上の正のバースがトランジスタ330を「オン」にし、画素のノードAを $V_{ss}$ 、例えば+10Vまでプリチャージする。次にデータラインが、前行の画素へデータを書き込むため、そのベースライン値から変化し、そのベースラインへ戻る。これは考慮中の画素への正味効果を持たない。

【0027】第二フェーズはオートゼロフェーズである。現在の行のAZラインとSELECTラインが高くなり、トランジスタ340、350を「オン」にし、トランジスタN1 310のゲートを落とし、ターンオン電圧へと自己バイアスをかけ、LEDに極くわずかな電流を流す。このフェーズにおいて、LEDのターンオン

電圧とN1の閾値電圧の合計がN1のゲートに保存される。N1とN2とはごく接近して配置できるので、それらの初期閾値電圧は極めて類似している。更に、これら2個のトランジスタのソースに対するゲート電圧 $V_g$ は同じはずである。TFTの閾値電圧のドリフトはTFTの全寿命にわたって $V_g$ のみに依存するので、これらデバイスの閾値電圧はTFTの全寿命にわたって追従すると見なすことが出来る。従って、N2の閾値電圧もそのゲート上に保存される。オートゼロ化の完了後、オートゼロラインはロー（low）に戻る一方、選択ラインはハイ（high）のままである。

【0028】第三フェーズはデータ書き込みフェーズである。データはベースライン電圧を超える電圧としてデータラインへ印加され、コンデンサを介して画素に書き込まれる。次に選択ラインがローに戻り、データ電圧、プラスLEDターンオン電圧、プラスN2の閾値電圧の合計が、残りのフレームに関してノードBに保存される。保存されたデータがリークによって失われないように、ノードBから $+V_{ss}$ までのコンデンサを使用できることに注目すべきである。

【0029】要するに、オートゼロフェーズの間、細電流（trickle current）を使用して、LEDのターンオン電圧とN2の閾値電圧が「測定」され、ノードBに保存される。このオートゼロフェーズは、本質的には駆動電流が極めて小さい電流駆動モードの作動である。オートゼロフェーズの後の書き込みフェーズになって初めて、印加されたデータ電圧を使用してLEDに増分が与えられる。従って、本発明は、電圧駆動または電流駆動よりはむしろ、「ハイブリッド駆動」を有するということが出来る。ハイブリッド駆動方法は、電圧駆動および電流駆動における欠点がなく、両者の長所を組み合わせるものである。LEDのターンオン電圧とTFTの閾値電圧の変動は、電流駆動における場合と全く同様に補正される。同時に、ディスプレイ上のすべてのラインは電圧によって駆動されるので、高速で駆動することが出来る。

【0030】注目すべきことに、データライン360に印加されるデータ電圧の増分は、LED304全体にわたって直接現れるのではなく、N2（320）とLEDの $V_g$ 間に分割される。このことは単に、データ電圧からLED電圧への非線型のマッピングがあることを意味する。このマッピングは、LED電圧からLED電流への非線型のマッピングと組み合わせられて、データ電圧からLED電圧への全体の伝達関数を発生するが、これは単調で、上記のようにディスプレイの全寿命にわたって安定している。

【0031】現在の画素構造300の利点は、閾値が補正されない画素におけるトランジスタ（N3、N4およびN5）がフレームあたり1列時間のみオンとなるためデューティサイクルが極めて短く、認識できるほどには

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シフトしないと予想されることである。更に、N2は、LEDの現在パスにおける唯一のトランジスタである。このパス上で直列接続されたトランジスタは、ディスプレイ効率を劣化させるか、あるいは未補正のTFT閾値シフトによる問題を発生する可能性があり、もしも一つの列上の全部の画素によって共有されると、縦方向の著しいクロストークをもたらす可能性がある。

【0032】選択パルスとオートゼロ(AZ)パルスは行スキナによって形成される。列データはAZパルス同士間のタイムスロットにおいて(任意の)一定ベースライン電圧に加えて印加される。選択信号の下降エッジは、データライン上でデータが有効である間に発生する。直接サンプル・タイプまたはチョップト・ランプ・タイプのいずれかの各種の外付けまたは内蔵の列スキナが、このタイミングによってデータを発生することが出来る。

【0033】上記の画素構造によれば、有機LEDを使用して大型の直視ディスプレイを造ることが出来る。もちろん、現在の画素構造は、駆動電流を必要とするディスプレイ要素を使用する任意のディスプレイ技術にも、特にディスプレイ要素またはTFTのターンオン電圧がシフトするかまたは不均一である場合、適用可能である。

【0034】図5は、本発明によるアクティブマトリックスLED画素構造500の好ましい実施態様の略図である。この画素構造500は、図3の画素構造300に類似であるが、ここでは2個のトランジスタの代わりにショットキダイオード1個を使用している。

【0035】画素構造300が有する可能性のある欠点の一つとして、1画素あたり5個のトランジスタを使用していることが挙げられる。すなわち、各画素に多数のトランジスタを使用しているので、画素のフィルファクタ(fill factor)(アクティブプレートを通るボトム側放出を想定して)およびその収率(yield)にも影響を及ぼす可能性がある。従って、画素構造300は、各画素に1個のショットキダイオードのみを使用してトランジスタ数を5個から3個に減らしつつ、且つ上記と同じ機能を果たす。

【0036】図5において、画素500は3個のNMOSトランジスタN1(510)、N2(520)、N3(530)、1個のコンデンサ502、1個のショットキダイオード540、およびLED(OLED)550(光要素)から成る。選択ライン570はトランジスタ530のゲートに接続されている。データライン560はコンデンサ502の一方の端子に接続されている。オートゼロライン580はトランジスタ520のゲートに接続されている。点灯ライン(VDDラインに類似)590はショットキダイオード540の一方の端子に接続されている。

【0037】コンデンサ502の一方の端子は(ノード

Aにおいて)トランジスタ520と530のドレインに接続されている。トランジスタ530のソースは(ノードBにおいて)トランジスタ510のゲートに接続されている。トランジスタ510のドレインはトランジスタ520のソースと、ショットキダイオード540の一方の端子に接続されている。

【0038】画素構造500も、下記のように、プリチャージフェーズ、オートゼロフェーズ、およびデータ書き込みフェーズの3フェーズで作動する。すべての点灯ラインはディスプレイの周囲で相互に結合されていて、プリチャージフェーズが始まる前に、これら点灯ラインは、約+1.5Vのプラスの電圧 $V_{th}$ に保持される。以下の説明においては、考慮中の行を「行i」と呼ぶ。各ライン上の波形も図6に示す。

【0039】第一フェーズはプリチャージフェーズである。プリチャージは、オートゼロ(AZ)ラインがトランジスタN2をオンにし、選択ラインがトランジスタN3をオンにすると開始される。このフェーズは、データラインがリセットレベルにあるとき行なわれる。ノードAとBにおける電圧はトランジスタN1のドレインと同じ電圧まで上昇するが、これは $V_{th}$ より低いダイオード降下である。

【0040】第二フェーズはオートゼロフェーズである。次に、点灯ラインがアースに落ちる。このフェーズ中、アレイ上のすべての画素は短時間暗くなる。ここで、ショットキダイオード540がトランジスタN1のドレインを、アースされた点灯ラインから絶縁して、N1のオートゼロ化が始まる。ノードBがトランジスタN1の閾値電圧プラスLED550のターンオン電圧にほぼ等しい電圧に達すると、AZラインを使用してトランジスタN2を「オフ」にし、点灯ラインは $V_{th}$ に戻る。選択されなかった行のすべての画素が再び点灯する。

【0041】第三フェーズはデータ書き込みフェーズである。次に、行iに関するデータがデータラインに印加される。ノードAとBにおける電圧上昇が、データラインのリセット電圧レベルとデータ電圧レベル間の差を等しくする。このようにして、トランジスタN1の閾値電圧とLEDのターンオン電圧の変動が補正される。ノードBにおける電圧が落ち着いた後、行iに関する選択ラインを使用してトランジスタN3をオフにし、データラインがリセットされる。これで次のフレームまで適切なデータ電圧が画素に保存される。

【0042】以上、先に述べた5トランジスタ画素の利点を持ちつつも、トランジスタ数の少ない、OLEDディスプレイ用3トランジスタ画素について説明した。更なる利点として、5トランジスタ画素には、オートゼロ化とLED駆動とに別々のトランジスタを使用されることである。画素300が適切に作動するには、これら2個のトランジスタの初期閾値が一致し、寿命の全期間に

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わたって同じようにドリフトすることが必要である。最近の実験データが示唆するところによれば、(これらトランジスタのように) T F T 同士のドレイン電圧が互いに異なると、両 T F T は同様にはドリフトしない。従って、画素 500 は、適切なオートゼロ化が保証されるように、LED を駆動する同じトランジスタ上でオートゼロ化を行なう。

【0043】図7は、本発明によるアクティブマトリックスLED画素構造700の代替実施態様の略図である。この画素構造700は、図3の画素構造300に類似するが、更に正確なオートゼロ電圧を発生する。

【0044】すなわち、図3において、オートゼロ化は、各プリチャージサイクルが図3に示すように大きなプラス電荷 $Q_{pc}$ を画素300のノードAに注入するという事実から生ずる。プリチャージフェーズ中、ノードA上のキャパシタンスのほとんどすべてはコンデンサ $C_{data}$ からであり、ノードAに注入される電荷は式(1)で表される。

【0045】

【数1】

$$Q_{pc} \equiv C_{data} (V_{DD} - V_A) \quad (1)$$

【0046】ここで $V_A$ は、プリチャージフェーズが始まる前のノードAにおける電圧である。 $V_A$ は、画素300に予め与えられたデータ、N3(300)の閾値電圧、およびLED304のターンオン電圧に左右される。 $C_{data}$ が大きなキャパシタンス(約1 pF)であるので、 $Q_{pc}$ も10ピコクーロン(picocoulomb)程度と大きい。

【0047】画素300が安定したオートゼロレベルにあるとき、 $Q_{pc}$ はオートゼロフェーズ中、N1(300)とLED304とを流れて流れる。オートゼロ間隔(インタバル)は短いので(約10  $\mu$ sec)、N1にはその閾値電圧より高いゲート対ソースオートゼロ電圧が残る可能性があり、同様にLEDもそのターンオン電圧を上回ってオートゼロ化する。このように、オートゼロ化プロセスにおいては、ノードAとノードBで、真のゼロ電流オートゼロ電圧ではなく、その近似値を発生する可能性がある。

【0048】注目すべきことは、N1とLEDを通る正確なゼロ電流に対応する真のゼロ電流オートゼロ電圧を発生させる必要がないという点である。本発明において、微弱な電流(約10ナノアンペア)をN1300とLED304とを流すことの出来るオートゼロ電圧を得ることが望ましい。オートゼロ間隔(インタバル)は約10  $\mu$ secであるので、 $Q_{pc}$ は約0.1ピコクーロン程度のはずである。上記のように、 $Q_{pc}$ は約10ピコクーロンである。

【0049】このように大きな $Q_{pc}$ の効果として、画素の安定オートゼロ電圧が閾値電圧とターンオン電圧の合

計をはるかに上回る可能性がある。この状態そのものは、もしも過剰なオートゼロ電圧がディスプレイ全体にわたって均一であれば、問題にはならない。すなわち、すべてのデータ電圧を相応にオフセットすることによって、この効果に対処することが出来る。

【0050】しかし、もしも $Q_{pc}$ が大きいのみならず、前のデータ電圧とオートゼロ電圧そのものに左右される場合、問題を生ずる可能性がある。この状態がもしもディスプレイ内で発生すると、すべての画素のオートゼロ電圧が大幅に過剰になるのみならず、過剰電圧の大きさが画素ごとに異なる可能性がある。実際、そのような条件下では、画素300のオートゼロ化によって均一なディスプレイを作ることが出来ない。

【0051】この問題に対処するため、画素700はプリチャージ $Q_{pc}$ を極めて小さい値に下げることが出来る。また、オートゼロ化に実際に必要な電荷に応じて $Q_{pc}$ を変化させることの出来る「可変プリチャージ」方法を開示する。要するに、現在のオートゼロ電圧が低すぎる場合、オートゼロ電圧を所望の値にまで上げるため、 $Q_{pc}$ はその最小値、約0.1ピコクーロンとなる。しかし、現在のオートゼロ電圧が高すぎると、 $Q_{pc}$ は実質的にゼロになり、オートゼロ電圧が急速に下がることを可能にする。

【0052】図7を参照すると、画素700は、5個のNMOSTランジスタ、N1(710)、N2(720)、N3(730)、N4(740)、N5(750)と、コンデンサ702と、LED(OLED)704(光要素)とから成る。選択ライン770はトランジスタ710のゲートに接続されている。データライン760はコンデンサ702の一方の端子に接続されている。オートゼロライン780はトランジスタ740のゲートに接続されている。 $V_{DD}$ ライン790はトランジスタ720と750のドレインに接続されている。画素アレイ内の前の行からのオートゼロライン782はトランジスタ750のゲートに接続されている。

【0053】本発明において、前の行からのオートゼロラインを第二選択ラインとすることが出来ることが特徴である。すなわち、現在の画素のタイミングを、第二選択ラインを必要とせずに前の行からのオートゼロライン782を利用できるようなタイミングにして、現在の画素の複雑さとコストを低減することが出来る。

【0054】コンデンサ702の一方の端子は(ノードAにおいて)トランジスタ710のドレインに接続されている。トランジスタ710のソースは(ノードBにおいて)トランジスタ720、730のゲートに接続され、トランジスタ740のソースに接続されている。トランジスタ740のドレインは(ノードCにおいて)トランジスタ750のソースとトランジスタ730のドレインに接続されている。最後に、トランジスタ730、720のソースはLED704の一方の端子に接続され

ている。

【0055】更に具体的に、画素700は、トランジスタN3(730)のドレインであるノードCにプリチャージ電圧が印加されること以外は、画素300に類似する。更に、図8に示すようないくつかのタイミング変更もある。以下に、画素700の作動を3フェーズの段階に分けて説明する。

【0056】第一フェーズは前のラインタイム中、すなわちデータが前の行の画素に印加される前に行なわれるプリチャージフェーズである。選択ライン上のプラスの10 パルスがN1を「オン」にし、これによってノードAとBが互いにショートされ、画素700の状態が、直前のオートゼロフェーズの後の状態に戻る。すなわち、画素は、画素の適切なオートゼロ電圧の最近の推測値である、データに依存しない電圧に戻る。N1が「オン」である間、前の行ラインからのオートゼロライン782上の正のパルスがトランジスタN5を「オン」にし、これによってノードCを $V_{dd}$ にプリチャージする。次に、トランジスタN1とN5が「オフ」とされる。

【0057】トランジスタN1とN5のオン、オフの相対的タイミングは、あまり重要ではないが、トランジスタN1は、トランジスタN5がオフになる前にオンとしなければならない。そうしないと、トランジスタN3が旧データ電圧に応じて依然としてオンのままとなり、ノードCへ注入された電荷がトランジスタN3を経てリークしてしまう可能性がある。

【0058】プリチャージフェーズの後、電荷 $Q_{rc}$ はノードCにおいて、トランジスタN3、N4、N5のゲート対ソース/ドレインのキャパシタンス上に保存される。これらキャパシタンスの合計は極めて小さく(約10 fF)、また、プリチャージ間隔がノードCを約10 V上昇させるので、 $Q_{rc}$ は当初、約0.1ピコクーロンである。しかしこの電荷は、前のオートゼロ電圧の真のオートゼロ電圧に対する近似精度によって変化する割合で、オートゼロフェーズの前にノードCからリークする。従って、オートゼロ化のためにはどれ程の電荷量が必要かということ次第で、 $Q_{rc} \leq 0.1$ ピコクーロンの関係はより精確に示されることになる。これは可変プリチャージ特徴である。直前のオートゼロ電圧が低すぎる場合、N3はプリチャージフェーズ後、非導通となり、 $Q_{rc}$ はその最大値に留まるはずであり、オートゼロフェーズ中、オートゼロ電圧をその要求レベルに向かって上昇させる。直前のオートゼロ電圧が高すぎる場合、N3は導通し、 $Q_{rc}$ はオートゼロフェーズが始まるまでにはリークし、オートゼロ電圧の急低下が可能になる。

【0059】トランジスタN1とN5の相対的タイミングは重要ではないが、好ましいタイミングを図8に示す。プリチャージに要する時間を最短にするため、2個のトランジスタN1とN5は同時にオンとされる。N1はN5より前にオフとされるが、これにより、ノードC

からの $Q_{rc}$ の(意図的な)リークは、N1をオフにすることによって容量的に押し下げられたノードB電圧に対応する。これにより、ノードCからの $Q_{rc}$ のリークは、画素にゼロデータが印加されたときに等しいノードB電圧に確実に対応する。

【0060】要するに、画素700は、画素300に比してより効果的なオートゼロ化を可能にする画素のプリチャージ手段を提供する。具体的には、画素700のオートゼロ化は、より正確、迅速、かつデータに対して独立性である。コンピュータシミュレーションによる確認では、画素700は、オートゼロ化が良好であり、100,000時間の作動寿命の全期間にわたってほぼ一定のOLED電流対データ電圧特性を維持することが出来る。

【0061】図9は、本発明の他の実施態様であるアクティブマトリックスLED画素構造900の略図である。画素構造900は、図7の画素構造700に類似しているが、追加の $V_{precharge}$ ライン992を備え、LED供給電圧 $V_{dd}$ を上げずにオートゼロ電圧範囲を拡張することが出来る点が異なる。画素のこの追加修正は、画素の寿命と効率を改善する。

【0062】以上説明した画素(200、300、700)は、 $V_{dd}$ がプリチャージ電圧であるので、オートゼロ電圧が $V_{dd}$ を超えることが出来ないという制限がある。しかし、トランジスタN2とN3の閾値電圧がトランジスタの寿命期間にわたってドリフトし、TFTドリフト電圧とOLEDターンオン電圧のドリフトを補正するため、オートゼロ電圧を $V_{dd}$ より高くする必要が生じる点に到達する。オートゼロ電圧は、より高い電圧に到達することは出来ないため、ディスプレイの均一性は急速に劣化し、ディスプレイの有用寿命の終りを告げる。 $V_{dd}$ を高くすれば、より高いオートゼロ電圧を達成できるが、 $V_{dd}$ はOLED駆動電源でもあるので、パワー効率が犠牲になる。

【0063】更に、パワー効率の改善のため、 $V_{dd}$ を下げてトランジスタN2をライン形領域で作動させると、オートゼロ電圧の範囲は更に制限される。(もちろん、そのようにすると飽和状態で作動させた場合よりN2を大きくする必要がある。)この場合、短時間の作動の後、オートゼロ電圧は $V_{dd}$ より高いレベルに到達する必要があるため、駆動寿命は極めて短くなる。

【0064】図9を参照すると、画素700に、オートゼロ電圧に対する制限をなくし、それによって $V_{dd}$ を十分に上回ることを可能にするオプションの変更が組込まれている。画素900は、列ライン992が追加され、それがトランジスタ950のドレインに接続されている以外は、画素700と同じである。

【0065】列ライン992は、DC電圧 $V_{precharge}$ をすべての画素に運ぶため、アレイに追加されている。これらすべての列ラインは、ディスプレイの端で相互接

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続されている。 $V_{\text{precharge}}$  を  $V_{\text{d}}$  より高いレベルに上げることによって、画素 900 は、 $V_{\text{precharge}}$  より高い電圧にプリチャージを行ない、オートゼロ化することが出来る。の高い値は、ディスプレイ効率にほとんど影響を及ぼさない。

【0066】各  $V_{\text{precharge}}$  ライン 992 は、画素の隣接する列との共有が可能であることに注目すべきである。この  $V_{\text{precharge}}$  ラインはまた、行ラインとして走らせ、隣接する行との共有が可能である。

【0067】要するに、オートゼロ電圧の範囲を  $V_{\text{d}}$  を超えて拡張するため、追加の電圧ラインを備えた OLED 画素を開示する。これによって OLED 駆動トランジスタは、パワー効率上必要な低い電圧で、場合によってはライン形領域においてすら、オートゼロ電圧を制限することなく、作動することが出来る。従って、長い作動寿命と高効率が達成できる。この変更を画素 700 について説明したが、最終的には、このオプション変更は、上記画素 200、300 を含み、それらに限らない他のオートゼロ画素構造にも実施可能である。

【0068】上記各画素構造は、OLED ディスプレイ用として、画素におけるトランジスタ閾値電圧変動と OLED ターンオン電圧変動が補正されるように設計されているが、これら画素構造は、画素の外部で発生する不均一性に対処するようには設計されていない。この画素は、ディスプレイプレートの外部からでも、ディスプレイに一体化した状態でも、従来の列駆動回路に使用可能であることが指摘された。

【0069】残念ながら、一体型データドライバは、外付けドライバほど精度がよくないのが普通である。市販の外付けドライバでは  $\pm 12 \text{ mV}$  の精度を達成できるが、一体型ドライバでは  $\pm 50 \text{ mV}$  の精度を達成できないことが判明している。一体型ドライバに特有なタイプの誤差は、オフセット誤差、すなわち、すべてのデータ電圧に加えられる、データ非依存性の DC レベルである。このオフセット誤差は不均一、すなわち DC レベルの値はデータドライバごとに変動する。液晶ディスプレイはオフセット誤差を許容する傾向がある。その理由は、フレームが順次反対極性で駆動され、あるフレームでオフセット誤差が液晶をわずかに暗くし、次のフレームで明るくするが、平均的にはほぼ正確で、交互の誤差は目で認識できないからである。しかし、OLED 画素は単一極性データによって駆動される。従って、オフセット誤差の二極消去は発生せず、一体型スキャナを使用すると深刻な不均一性問題が発生する可能性がある。

【0070】図 10 は、列トランジスタ 1020 を介してデータドライバ 1010 に接続された本発明のアクティブマトリックス LED 画素構造 300 の略図である。本発明は、OLED ディスプレイ用の一体型データスキャナにおけるオフセット誤差の消去方法を説明する。すなわち、この方法は、画素がデータラインに容量的に接

続され、例えば上記の画素 200、300、500 および 700 のようなオートゼロフェーズを有する任意の画素とともに作動するように設計されている。

【0071】図 10 を参照すると、上記の画素 300 は、OLED 要素の輝度を確定するため画素にアナログレベルを供給するデータラインに接続されている。図 10 において、データラインは、データライン上に電圧を設定するためのチョップト・ランプ技法 (chopped ramp technique) を使用するデータドライバによって駆動される。このアプローチ (技法) には、データライン上にオフセット誤差を発生させる種々の誤差源が存在する。例えば、電圧比較器が切り替わる時間は、比較器の最大スルーレート (slew rate) 次第で変動する可能性がある。また、最大スルーレートは大幅に変動することが、実験によって観察されている。オフセット誤差は、画素に保存されている電圧に影響を及ぼす。オフセット誤差はまた、不均一であるので、ディスプレイ全体にわたって輝度の変動をもたらす。

【0072】本発明においては、画素がそれ自体の内部閾値誤差を消去するためのオートゼロ化の期間を、データスキャナのオフセット誤差のキャリブレーションにも使用する。種々のラインの波形を図 11 に示す。

【0073】すなわち、これは実際のデータ電圧を印加するのと同じ列ドライバを使用してデータライン上に基準ブラックレベルを設定することによって達成される。画素のオートゼロフェーズ中に印加されるこの基準ブラックレベルは、実際のデータ電圧が設定されるのと全く同じやり方でデータライン上に設定される。すなわち、データランプ (data ramp) は電圧比較器によって定められる時間においてチョップされる。従って、画素のコンデンサ C を横切る電圧は画素のターンオン電圧と、ブラックレベルにオフセット誤差電圧をプラスした組合せによって定まる。基準ブラックレベルは、オートゼロフェーズの全期間、維持される。実際のデータが画素に印加されると、データスキャナオフセット誤差は画素のコンデンサ上に保存された電圧によって消去される。

【0074】この技法は、チョップト・ランプを使用する一体型スキャナのみならず、列上へ直接サンプリングを使用するスキャナにも適用可能である。直接サンプリングの場合、誤差は、(大きな) 列トランジスタがオフにされるとき、ゲート信号のデータラインへの不均一容量フィードスルーによって発生する。このトランジスタの閾値電圧変動は、チョップト・ランプ・データ・スキャナによって生じる不均一オフセット誤差と全く同様に、不均一オフセット誤差を生じる。

【0075】従って、これは同様に補正できる。ブラック基準電圧は、画素のオートゼロフェーズ中、列に書き込まれる。一行のすべての画素が同時にオートゼロ化するので、このブラックレベルは、ラインタイム開始時にすべてのデータ列に同時に書き込まれる。ブラックレベ

ルはオートゼロフェーズの全期間中、維持される。チョップト・ランプ・スキナの場合のように、実際のデータが画素に印加されると、オフセット誤差は画素キャパシタに保存されている電圧によって消去される。しかし、オフセット誤差の補正に必要な時間オーバーヘッドは、チョップト・ランプ技法を使用するよりも、直接サンプリング技法を使用する方が少ないように思われる。

【0076】データドライバ誤差を補正するための本発明の方法は、別の方法よりも輝度の均一性のはるかに良好な有機LEDディスプレイの作成を可能にするはずである。ここに説明した方法と、上記いずれかのオートゼロ化画素を使用して、ディスプレイの全寿命にわたって均一性に目立った劣化のない、8ビットの輝度均一性が達成可能である。

【0077】上記開示では、ディスプレイの輝度の不均一性に対処するため使用することの出来る複数の画素構造を記述したが、代替のアプローチ(技法)として、外付け手段によって不均一性を補正することが出来る。より具体的には、下記の開示は、ディスプレイの輝度の不均一性に対処するための方法と外付けキャリブレーション回路を説明する。要するに、すべての画素について不均一性を測定し保存し、測定した不均一性を使用して、データ(例えばデータ電圧)のキャリブレーションを行なうことが出来る。

【0078】このように、以下の説明においては、図2の従来の画素構造を使用するが、本発明の外付けキャリブレーション回路と方法は、上記の画素300、500、700を含み、これらに限らない他の画素構造にも使用することが出来る。しかし、本発明の外付けキャリブレーション回路と方法によって不均一性に対処すれば、より簡単な画素構造をディスプレイに採用でき、それによってディスプレイの収率とフィルファクタ(fill-factor)を増加させることが出来る。

【0079】図12は、画素200のアレイ(集合)を相互接続して画素ブロック1200とした状態の略図である。図2を参照すると、動作の際、データは、アクティブマトリックスディスプレイで普通に行なわれる方法で、画素アレイに書き込まれる。すなわち、選択ラインを高く駆動することによって画素の一行が選ばれ、それによってアクセストランジスタN1がオンとなる。各データラインにデータ電圧を印加することによって、この行の各画素にデータが書き込まれる。ノードAにおける電圧が安定した後、選択ラインを低く駆動することによって、この行が選択から解除される。このデータ電圧は、次のフレームでこの行が選択されるまで、ノードAに保存される。N1がオフにされている間に、ノードAから多少の電荷リークの可能性があるので、不適当なレベルの電圧降下を防ぐため、ノードAに蓄電コンデンサが必要になるかも知れない。図中の破線は、電圧降下に対処するための、コンデンサの接続方法を示す。しか

し、そのような追加のコンデンサを不要にするほど十分なキャパシタンスがN2のゲートに関連して存在するかもしれない。

【0080】注目すべきことに、OLEDの輝度Lは、その電流Iにほぼ比例し、比例定数はディスプレイ全面にわたってかなり安定している。従って、良好に確定されたOLED電流を発生させれば、ディスプレイは視覚的に均一になる。

【0081】しかし、プログラムによって画素へ供給されるのは、OLED電流ではなくN2上のゲート電圧である。TFT閾値電圧と相互コンダクタンス(transconductance)は、OLEDの電氣的パラメータが呈するように、ディスプレイ全体にわたる多少の初期不均一性を呈する可能性がある。更に、TFT閾値電圧は、OLEDターンオン電圧と同様に、バイアス温度ストレス条件下で増加することが周知である。従って、これらのパラメータは、当初不均一であり、各画素の個々のバイアス履歴に依存する態様で、画素の全寿命にわたって変化するものと期待される。これらパラメータを補正せずにN2のゲート電圧のプログラムを作成すると、ディスプレイは当初から不均一で、ディスプレイの全寿命にわたって不均一性が次第に増大する。

【0082】本発明は、TFTとOLEDの電氣的パラメータが補正され、それによって良好に確定されたOLED電流が画素アレイ内に生じるような方法である。N2に印加されるデータ電圧を補正するための方法を以下に説明する。

【0083】図2と図12は、データラインに並列に配置されたVDD供給ラインを有する画素アレイを示す。

(好ましい実施態様において、VDDラインは選択ラインに並列に配線することが出来る。)このようにして、画素が2個またはそれ以上の隣接する列で各VDDラインを共有して、VDDラインの本数を減らすことが出来る。図12は、VDDラインがディスプレイの周囲で結束されてブロック化された状態を示す。各画素ブロック1200に含まれるVDDラインの数は、1本と少なくとも、ディスプレイ上のVDDラインの全数のように多くてもよい。しかし、好ましい実施態様において、各画素ブロック1200は、約24本のVDDライン、すなわち約48の画素列を含む。

【0084】図13は、ディスプレイ1310とディスプレイコントローラ1320との相互接続の略図である。ディスプレイ1310は複数の画素ブロック1200から成る。ディスプレイコントローラ1320は、VDDコントロールモジュール1350、測定モジュール1330、および種々のI/Oデバイス、例えばA/Dコンバータや、画素パラメータを保存するためのメモリーから成る。

【0085】各画素ブロックは、図12、13に示すように、ディスプレイの端において検知ピン(VDD/S

ENSE) 1210に接続されている。通常のディスプレイ作動中、検知ピン1210は、例えば10ないし15ボルトの外部 $V_{ss}$ 電源に切り替えられ、これによってOLEDエレメントを点灯するための電流をディスプレイに供給する。更に具体的には、各VDD/SENSEピン1210は、ディスプレイコントローラ1320において、一對のpチャンネルトランジスタP1(1352)とP2(1332)および電流検知回路1334に接続されている。通常の作動中、ディスプレイコントローラからのILLUMINATE信号がP1を作動させてVDD/SENSEピンを $V_{ss}$ 電源に接続する。典型的な実施態様において、P1を通る電流は約1mA/列と予想される。

【0086】TFTとOLEDのパラメータを補正するため、特別測定サイクル中、各画素のパラメータに関する情報を収集するため、MEASURE信号を介して外付け電流検知回路1334を作動させる。収集された情報は、通常のディスプレイ作動中、必要なOLED電流を実現するのに適したデータ電圧の計算および調整に使用される。

【0087】更に具体的には、特定の画素の測定サイクル中、画素ブロック内の他のすべての画素は、それらに低いデータ電圧(例えばゼロ以下)を印加することによって、オフにされ、それによって、「オフ」画素からの電流の引き出しを確実に無視できるようにする。次に、対象とする画素によって引き出された電流が、1個以上の印加データ電圧に応じて測定される。各測定サイクル中、データパターン(すなわち、あるブロック中で、1個の画素のみがオンで、その他すべての画素がオフ)が、通常の方法で画素に印加され、データドライバ回路によってデータがDATAラインに印加され、行が一つずつ選択される。このようにして、ディスプレイが複数の画素ブロックに区画されるので、各画素ブロック内の少なくとも1個の画素をオンにすることによって、複数の画素を測定することが出来る。

【0088】各画素ブロック内の対象画素によって引き出された電流は、ILLUMINATEラインとMEASUREラインを、VDD/SENSEピン1210をVDD電源から切り離すとともに検知ピンをP2経由で電流検知回路1334のインプットに接続するレベルに駆動することによって外部からP2において測定される。画素電流は1ないし10 $\mu$ Aと予想される。電流検知回路1334は図13に相互インピーダンス増幅器として示してあるが、電流検知回路を他の形態で実施することも出来る。本発明においては、増幅器は入力端における電流に比例した電圧を出力端に発生する。この測定された情報は、I/Oデバイス1340によって収集され、そこでこの情報はデジタル形式に変換され、データ電圧のキャリブレーション用に保存される。電流検知回路1334内の抵抗器は約1メガオームである。

【0089】複数の電流検知回路1334が画素ブロックと一對一の対応で示してあるが、マルチプレクサ(multi-plexer、不図示)を使用すれば、電流検知回路の数を減らすことが出来る。すなわち、複数のVDD/SENSEピンを単一の電流検知回路1334に多重化することが出来る。極端な場合、単一の電流検知回路を全ディスプレイ用に使用することが出来る。VDD/SENSEピンをこのように検知回路に多重化すると、外付け回路の複雑さは低減できるが、ディスプレイ測定時間は長くなる。

【0090】画素測定サイクルを行なうためには、通常のディスプレイ作動を中断しなければならないので、画素測定は、見る人を出来るだけ邪魔しないようにタイミングを図らねばならない。画素パラメータは徐々に変化するので、特定の画素を頻繁に測定する必要はなく、測定サイクルは長期間にわたって分散することが出来る。

【0091】すべての画素を同時に測定する必要はないが、可変測定ラグ(遅延)に基づく不均一性を避けるためには、同時測定が有利である。これは、ディスプレイモジュールが「オン」または「オフ」されるとき、すべての画素を迅速に測定することによって達成可能である。ディスプレイモジュールが「オフ」のとき画素を測定すれば、通常の作動の邪魔にはならないが、長い「オフ」期間後、保存された画素パラメータはもはや均一性を保証しないかも知れないという欠点がある。しかし、中断しない電源が利用可能であれば(例えばスクリーンセ이버モードにおいて)、ディスプレイが(ユーザーの観点から)「オフ」である間に測定サイクルを周期的に行なうことが出来る。もちろん、ディスプレイモジュールが「オン」のときすべての画素の迅速測定を含まない任意のオプションでは、パワーが「オフ」のとき測定情報を保存するための不揮発性メモリーが利用可能であることが必要である。

【0092】もしも画素測定情報が利用可能であれば、ディスプレイの不均一性の種々の原因を補正するため、データ電圧の補正またはキャリブレーションをディスプレイに適用することが出来る。例えば、トランジスタの閾値電圧変動とOLEDターンオン電圧変動に対処するため、データ電圧の補正を行なうことが出来る。従って、上記およびその他のディスプレイ不均一性を補正することの出来る複数の方法を以下に説明する。これらの方法を使用すれば、ディスプレイに数個の、そのうちのいくつかは大きな不均一性の原因があっても、均一な高画質ディスプレイを提供することが出来る。

【0093】この補正方法を説明するため、ディスプレイには図2の画素構造を使用するものと仮定する。しかし、この補正方法は、他の任意の画素構造を使用したディスプレイにも適用できる。

【0094】図2を参照すると、ノードAに保存された電圧はN2のゲート電圧であり、従ってN2とLEDと

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を通る電流を確定する。N2上の電圧を変化させることによって、LED電流を変化させることが出来る。N2上のゲート電圧とLEDを通る電流との関係を考慮する。ゲート電圧 $V_g$ は、以下の式(2)の様に、N2のゲート対ソース電圧 $V_{gs}$ と、LEDを横切る電圧 $V_{diode}$ の二つに分割することが出来る。

【0095】

【数2】

$$V_g = V_{gs} + V_{diode} \quad (2)$$

【0096】飽和状態のMOSTランジスタのドレイン電流は以下の式(3)で表される。

【0097】

【数3】

$$I = \frac{2}{k} (V_{gs} - V_t)^2 \quad (3)$$

【0098】ここで、 $k$ はデバイスの相互コンダクタンスパラメータ、 $V_t$ は閾値電圧である(ライン形領域における作動は下記参照)。従って、以下の式(4)が得られる。

【0099】

【数4】

$$V_g = V_t + \sqrt{\frac{2I}{k}} + \sqrt{\frac{I}{A}} \quad (7)$$

【0106】OLEDのI-V特性を表すため、他の関数形式を使用することも出来るが、上記の式によれば、ゲート電流とダイオード電流との間の異なる関数関係をもたらしことに注目すべきである。しかし、本発明は、上記のOLEDのI-V特性の詳細な関数形に限定されず、従って、任意のダイオード的特性に関して作動するように適応させることが出来る。

【0107】OLEDの輝度 $L$ は、その電流 $I$ にほぼ比例し、比例定数は、ディスプレイ全面にわたって安定かつ均一である。良好に確定されたOLED電流を発生させることが出来れば、ディスプレイは視覚的に均一となる。しかし、以上説明したように、画素は電流 $I$ ではなく、電圧 $V_g$ を使用してプログラムされている。問題は、OLEDのパラメータ $A$ と $m$ の他に、TFTのパラメータ $V_t$ と $k$ がディスプレイ全面にわたって、ある程度の初期不均一性を呈するという点である。更に、 $V_t$ がバイアス温度ストレス条件下で増加することは周知である。OLEDパラメータ $A$ は、OLEDのターンオン電圧に直接関連し、バイアスストレス下で減少することが知られている。OLEDパラメータ $m$ は、オーガニック・バンド・ギャップ内のトラップの分布に関連があり、OLEDの全寿命にわたって変化する。従って、これらのパラメータは初期に不均一であり、各画素の個々

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$$V_{gs} = \sqrt{\frac{2I}{k}} + V_t \quad (4)$$

【0100】OLEDを通る前向き電流は以下の式(5)で表される。

【0101】

【数5】

$$I = AV_{diode}^m \quad (5)$$

【0102】ここで、 $A$ と $m$ は定数である(Burrows 他 の J. Appl. Phys. 79(1996)参照)。従って、以下の式(6)が得られる。

【0103】

【数6】

$$V_{diode} = \sqrt[m]{\frac{I}{A}} \quad (6)$$

【0104】従って、ゲート電流とダイオード電流との全体的関係は、以下の式(7)で表される。

【0105】

【数7】

のバイアス履歴に依存してディスプレイの全寿命にわたって変化するものと予想される。これらのパラメータの変動を補正せずにゲート電圧をプログラムすると、ディスプレイは初期に不均一で、その全寿命にわたって不均一性が増大する。

【0108】実際に、不均一性の原因は他にもある。ゲート電圧 $V_g$ は、意図したデータ電圧 $V_{data}$ に必ずしも等しくない。むしろ、データドライバにおけるゲイン誤差とオフセット誤差、およびN1の選択解除から発生する(データ依存性の)フィードスルーが、これら二つの電圧に差異を生じさせる。これらの誤差原因も、不均一であり、かつ、ディスプレイの全寿命にわたって変動する。上記およびその他のゲイン誤差とオフセット誤差を、以下の式(8)で表す。

【0109】

【数8】

$$V_g = BV_{data} + V_0 \quad (8)$$

【0110】ここで、 $B$ と $V_0$ はそれぞれゲイン係数とオフセット電圧であり、ともに不均一であり得る。式(7)と(8)を組み合わせて整理すると以下の式(9)が得られる。

【0111】

【数9】

$$V_{data} = V_{off} + C\sqrt{I} + D\sqrt[m]{I} \quad (9)$$

【0112】ここで、 $V_{off}$ 、 $C$ 、 $D$ は前出のパラメータの組合せである。

【0113】本発明は、 $V_{off}$ 、 $C$ 、 $D$ 、および $m$ の変動を補正するため、意図する（入力）データ電圧を補正する種々の補正方法を提供し、それによって画素アレイ内における良好に確定されたOLED電流の発生を可能にする。パラメータ $V_{off}$ 、 $C$ 、 $D$ 、および $m$ の変動を補正するため、上記の外付け電流検知回路が、各画素に関する情報、すなわち単一の画素によって引き出された電流を外部から測定することが出来る。パラメータ $V_{off}$ 、 $C$ 、 $D$ 、および $m$ に関して測定された情報を使用して、本発明は、通常のディスプレイ作動中、必要なOLED電流を確定するため、式（9）に従って適切なデータ電圧 $V_{data}$ を計算する。

【0114】また、電流の測定値から4個のパラメータ $V_{off}$ 、 $C$ 、 $D$ 、および $m$ を正確に計算することは、コンピュータでは高価になり、複雑な繰り返し計算が必要になる。しかし、効果的な補正を維持しつつ計算の複雑さを低減する良好な近似を使用することが出来る。

【0115】好ましい実施態様において、上記のように4個ではなく、わずか2個のパラメータを使用して画素の不均一特性を表すことが出来る。式（9）の画素の電\*

$$V_{data} = V_{offset} + C\sqrt{I} \quad (10)$$

【0118】ここで、 $V_{offset} = V_{off} + D\sqrt[m]{I}$ は $D\sqrt[m]{I}$ を含み、 $V_{offset}$ と $C$ は画素ごとに変動する。

【0119】図14は、全画素のパラメータの測定によってディスプレイを初期化する方法1400のフローチャートである。方法1400は、ステップ1405から始まり、ステップ1410に進み、そこで、画素ブロック内の対象とする画素以外のすべての画素に、「オフ」データ電圧を印加する。

【0120】ステップ1420において、対象とする特定の画素の $V_{offset}$ と $C$ を求めるため、方法1400は二つのデータ電圧（ $V1$ と $V2$ ）を印加し、各データ電圧について電流を測定する。

【0121】ステップ1430において、電流 $I1$ と $I2$ の平方根が計算される。好ましい実施態様において、この計算のために平方根表が使用される。

【0122】ステップ1440において、 $V_{offset}$ と $C$ とが求められる。すなわち、二つの変数を求めるのに二つの式を使用することが出来る。次に、特定の対象画素の求められた $V_{offset}$ と $C$ を記憶装置、例えばメモリーに保存する。全部の画素の測定が終ると、メモリーはアレイ内の各画素について二つのパラメータ $V_{offset}$ と $C$ とを保存している。これらの値は、後に式（10）を使

\* 流電圧特性を参照すると、通常の点灯レベルにおいて、 $N2$ の $V_g$ に関する $C\sqrt{I}$ 項と、 $V_{diode}$ に関する $D\sqrt[m]{I}$ 項とは、ほぼ同じ大きさである。しかし、それらの画素電流への依存性は大きく異なる。 $m$ の値は約10であるので、普通の点灯レベルにおいては、 $D\sqrt[m]{I}$ は $C\sqrt{I}$ に比してはるかに弱い $I$ の関数である。例えば、 $I$ を100倍に増加させると、 $C\sqrt{I}$ は10倍になるが、 $D\sqrt[m]{I}$ は（ $m$ を10と仮定すると）1.58倍にしかない。すなわち、普通の点灯電流レベルにおいては、OLEDの $I-V$ 曲線はTFTの $I-V_g$ 曲線よりはるかに急勾配となる。

【0116】従って、普通の電流レベルにおいて、 $D\sqrt[m]{I}$ は電流に対して独立であり、その画素ごとの変動は単に一つのオフセット誤差として処理可能であるという近似が行なわれる。この近似は多少の誤差を持ち込むが、ディスプレイ全体の外観は大幅には劣化しない。従って、かなりの精度で、すべてのディスプレイの不均一性を、オフセットとゲインの変動として処理することが出来る。従って、（9）式は以下の式（10）の様に近似することが出来る。

【0117】

【数10】

用して $V_{data}$ のキャリブレーションまたは調整に使用することが出来る。方法1400は次にステップ1455において終了する。

【0123】測定される画素を通る電流は、 $D\sqrt[m]{I}$ が二つの測定点においてほぼ等しくなるように、十分に高くなければならないことに注目すべきである。この条件は、一方の測定を、システムが発生可能な最高データ電圧において行ない、次に他方の測定をわずかに低いデータ電圧において行なうことによって満足させ得ることが望ましい。

【0124】ディスプレイの初期化が行なわれると、ディスプレイモジュールに供給された生の入力ビデオデータを修正することが出来る。入力ビデオデータは、例えば（1）画素電圧、（2）ガンマ補正された画素輝度、または（3）画素電流といった種々のフォーマットで存在することが出来ることに注目すべきである。従って、入力ビデオデータのキャリブレーションまたは補正を行なうための、保存されたパラメータ $V_{offset}$ と $C$ の使用は、各特定のフォーマットに依存する。

【0125】図15は、画素電圧を表す入力ビデオデータの修正方法1500のフローチャートである。方法1500は、ステップ1505から始まり、ステップ1510へ進み、そこで対象画素に関して保存されたパラメ

ータ、例えば  $V_{\text{offset}}$  と  $C$  が取出される。

【0126】ステップ1520において、方法1500は、入力ビデオデータのキャリブレーションを行なうため、取出したパラメータを印加する。より具体的には、入力ビデオデータにはバイアスがかかっていない、すなわち、ゼロボルトはゼロ輝度を表し、ゼロより大きいデータはゼロより大きい輝度レベルを表すものと期待される。従って、電圧は  $C_0 \sqrt{I}$  に等しいと見なすことが出来る。ここで、 $I$  は必要電流、 $C_0$  は定数、例えば典型的な値は  $103 \text{ V} / \sqrt{\text{A}}$  である。入力ビデオデータがディスプレイモジュールに入る際の画素変動を補正するため、各画素について  $V_{\text{offset}} = V_{\text{off}} + C \sqrt{I}$  を、保存された  $V_{\text{offset}}$  と  $C$  に基づいて計算する。この計算は、ビデオデータに  $C/C_0$  を掛けることと、その結果に  $V_{\text{offset}}$  を加えることから成る。 $C_0$  による除法は、ビデオデータ  $V_{\text{data}}$  が既に一定の係数  $1/C_0$  によって縮小されていれば不要である。 $C$  による乗法は、デジタルロジックで直接、またはルックアップテーブルを使用して行なうことが出来る。例えば、後者の場合、 $C$  の各値は、ビデオデータの値がインデックスであるとともにテーブルエントリが乗法の結果であるテーブルを指定する。(あるいは、ルックアップテーブル内の入力ビデオデータと  $C$  の役割を逆にすることも出来る。)乗法が行なわれた後、デジタルロジックにより  $V_{\text{offset}}$  の急速加算が行なわれる。

【0127】ステップ1530において、得られた電圧  $V_{\text{data}}$ 、すなわち修正または調整された入力データは、画素アレイのデータドライバに送られる。方法1500は次にステップ1535で終了する。

【0128】ガンマ補正された輝度データの場合、入力ビデオデータは、 $L^{0.45}$  に比例する。ここで、 $L$  は輝度である。これは、CRT輝度-電圧特性に関して予め補正されたビデオデータでは典型的である。 $L^{0.45} = \sqrt{L}$  であり、また、OLED輝度はその電流に比例するので、データは  $\sqrt{I}$  に比例するものとして処理することが出来る。従って、計算は先に説明したゼロオフセット電圧に関する方法と同様な方法で行なうことが出来る。

【0129】図16は、画素電流、すなわち輝度を表す入力ビデオデータの補正方法1600のフローチャートである。方法1600は、ステップ1605から始まり、ステップ1610に進み、そこで測定された電流の平方根の値が求められる。すなわち、方法1600は、 $I$  を表すビデオデータが  $\sqrt{I}$  を発生するように処理されねばならないこと以外は、上記の方法1500と同じである。上記のように、この演算は、図14に示すように、画素電流測定値から画素パラメータ  $V_{\text{offset}}$  と  $C$  を求めるのに必要な平方根の値を与える表を使用して行なうことが出来る。ここで再びこの表を使用してビデオデータから  $\sqrt{I}$  を発生させる。

【0130】次にデータ補正ステップ1610ないし1

6.45は、ステップ1630において入力データに  $C$  を掛け、次に  $V_{\text{offset}}$  を加えて補正されたデータ電圧を求めること以外は、上記の方法1500と同一である。

【0131】あるいは、別の実施態様において、上記のように2個または4個のパラメータではなく、1個のみのパラメータを使用して画素の不均一特性を表すことが出来る。すなわち、単一のパラメータを使用して画素の不均一特性を表すようにして更に単純化を行なう。

【0132】更に具体的には、多くの場合、画素ごとのゲイン係数  $C$  の変動は小さく、 $V_{\text{offset}}$  のみが不均一性の有意の原因として残る。これは、TFT相互コンダクタンスパラメータ  $k$  と電圧ゲイン係数  $B$  が均一のとき発生する。この場合、各画素の  $V_{\text{offset}}$  のみを求めれば十分である。そうすると、データ補正は乗法を行わず(ゲイン係数が均一であると見なされるので)、オフセットパラメータの加算のみを行なう。

【0133】この単一パラメータ手法は、上記のオートゼロ化OLED画素構造に類似である。この単一パラメータ補正方法は、コンピュータ費用を低減するとともに、満足すべきディスプレイ均一性を生み出すはずである。しかし、ディスプレイの均一性保持が非常に重要な特定のディスプレイの使用に於ては、コンピュータの複雑さと費用が増しても、上記の2個または4個パラメータ方法を使用することが出来る。

【0134】ここでも、単一パラメータ抽出とデータ補正に関して、ディスプレイ初期化プロセスはデータのフォーマット(形式)に左右される。単一パラメータ手法は、ビデオデータが、(1)画素電圧、(2)画素電流、および(3)ガンマ補正された画素輝度、を表す場合に、ディスプレイの初期化とビデオデータの補正に使用することが出来る。

【0135】図17は、全画素のパラメータの測定によるディスプレイの初期化方法のフローチャートを示す。方法1700は、ステップ1705から始まってステップ1710へ進み、そこで、画素ブロック内の対象画素以外のすべての画素に「オフ」データ電圧が印加される。ステップ1720において、対象とする特定の画素に関する  $V_{\text{offset}}$  と  $C$  を求めるため、方法1700は、2個のデータ電圧( $V_1$ と $V_2$ )を印加し、各データ電圧ごとに電流を測定する。

【0136】ステップ1730において、電流  $I_1$  と  $I_2$  の平方根を計算する。好ましい実施態様において、この計算に平方根表を使用する。

【0137】 $C$  の値は均一であると考えられるので、それは理想的には、ディスプレイ内の任意の場所で2点測定を行なうことによって、求め得ることに注目すべきである。しかしこれは、対象画素が異常であるかも知れないので、問題を有するかもしれない。従って、2点測定は、各画素ごとに行なわれる。

【0138】ステップ1740において、 $C$  の平均値が



求められる。すなわち、各電流測定値に関する $\sqrt{I}$ を計算するための表を使用して、ディスプレイのCの平均値が計算できる。

【0139】ステップ1750において、各画素の電流測定値から平均値Cを使用して、各画素の $V_{\text{offset}}$ が求められる。このようにして、ディスプレイ全体にわたるCの小変動が $V_{\text{offset}}$ の計算によって部分的に補正される。上記理由により、各画素の電流の測定は、可能な最高データ電圧において測定することが望ましい。

【0140】最後にステップ1760において、各画素の $V_{\text{offset}}$ が記憶装置、例えばメモリーに保存される。次に、方法1700はステップ1765において終了する。

【0141】図18は、画素電圧を表す入力ビデオデータの補正方法1800のフローチャートである。方法1800は、ステップ1805から始まり、ステップ1810へ進み、そこで、対象画素に関して保存されているパラメータ $V_{\text{offset}}$ を取り出す。

【0142】ステップ1820において、方法1800は、取出したパラメータ $V_{\text{offset}}$ を使用して入力ビデオデータのキャリブレーションを行なう。より具体的には、保存された $V_{\text{offset}}$ の値に基づいて、各画素に関する $V_{\text{data}} = V_{\text{offset}} + V_{\text{data}}$ の値を計算する。

【0143】ステップ1830において、得られた $V_{\text{data}}$ 、すなわち補正された、または調整された入力データは画素アレイのデータドライバへ送られる。方法1800は次に、ステップ1835において終了する。

【0144】図19は、ビデオデータが画素電流を表す状況に関する全画素のパラメータの測定によるディスプレイの初期化方法1900のフローチャートである。方法1900は上記方法1700に酷似している。上記方法1700との相違は、方法1900が追加のステップ1950を取り入れて計算されたCの平均値を使用して、ゼロ・オフセットデータ電圧対画素電流の表を作成する場合である。この点から先の初期化とデータ補正プロセスにおいては、この表を使用することにより、平方根演算を行わない。この表は、平方根関数より高い精度で、画素の電流-電圧特性を表すものと期待される。この表は次に、後で使用するため、記憶装置、例えばメモリーに保存される。次に、個々の画素電流測定値を、この表に入れるためのインデックスとして使用して、個々の画素オフセット $V_{\text{offset}}$ を求める。

【0145】図20は、画素電流、すなわち輝度を表す入力ビデオデータの補正方法2000のフローチャート\*

$$V_{\text{data}} = V_{\text{off}} + C(I)I + D\sqrt{I} \quad (11)$$

【0152】ここで、 $C(I)$ はIの弱い関数である。ここでも、上記のように、オフセット項とゲイン係数のみを求めればよい程度に、電流が十分に高ければ、 $D\sqrt{I}$ 項を $V_{\text{off}}$ 項に含めることが出来る。しかし、オフ

\*である。方法2000は、ステップ2005から始まり、ステップ2010へ進み、そこで現在対象とする画素の $V_{\text{offset}}$ を記憶装置から取出す。

【0146】ステップ2020において、ゼロ・オフセットデータ電圧対画素電流の表を使用して入力ビデオデータ電流からゼロ・オフセットデータ電圧を求める。ステップ2030において、このゼロ・オフセットデータ電圧を、取出された $V_{\text{offset}}$ に加える。最後に、ステップ2040において、補正または調整された入力ビデオデータを画素アレイのデータドライバへ送る。

【0147】要するに、ビデオデータがディスプレイモジュールに導入されると、各電流に対応するゼロ・オフセットデータ電圧が $V-I$ 表内で検索される。次に、保存されている画素オフセットをゼロ・オフセット電圧に加算し、その結果がデータドライバへの入力となる。方法2000は次にステップ2045において終了する。

【0148】図21は、ビデオデータがガンマ補正された輝度データを表す状況に関する全画素のパラメータの測定によるディスプレイの初期化方法2100のフローチャートである。方法2100は、上記方法1900に酷似している。方法2100と上記方法1900との相違は、ステップ2150において、計算されたCの平均値を使用してゼロ・オフセットデータ電圧対画素電流の平方根の表を作成するときである。すなわち、ビデオデータは、 $\sqrt{I}$ を表すものとして近似させることが出来る。従って、Cの平均値を使用して $V_{\text{data}}$ 対 $\sqrt{I}$ のゼロ・オフセット表を作成し、この表をメモリーなどの記憶装置に保存する。

【0149】図22は、ガンマ補正された輝度データを表す入力ビデオデータの補正方法2200のフローチャートである。方法2200は、上記方法2000に酷似している。上記方法2000との相違は、 $V_{\text{data}}$ 対 $\sqrt{I}$ のゼロ・オフセット表において発生する。従って、要するに、入ってくるビデオデータを使用してゼロ・オフセットデータ電圧を探し、保存された画素オフセットをこれらの電圧に加える。

【0150】上記説明において、OLED駆動トランジスタN2が飽和状態で作動するものと見なしている。N2がライン形領域で作動するならば、類似の補正方法を使用することが出来る。その場合、画素の電流電圧特性は以下の式(11)で表される。

【0151】

【数11】

セット電圧のみを不均一と見なす単一パラメータ近似は、ゲイン係数 $C(I)$ が不均一なOLEDパラメータAとmを含むので、上記の飽和の場合に関する単一パラメータ近似ほど精度がよいとは予想されない。従って、

N2がライン形領域で作動するならば、2個パラメータ補正方法の方が単一パラメータ補正方法よりもはるかに性能がよいと思われる。

【0153】図23は、本発明の複数のアクティブマトリックスLED画素構造300、500、または700を備えたディスプレイ2320を使用したシステム2300のブロックダイヤグラムである。システム2300は、ディスプレイコントローラ2310とディスプレイ2320とから成る。

【0154】更に具体的には、ディスプレイコントローラは、中央処理装置CPU(2312)、メモリ2314、および複数のI/O装置(例えばマウス、キーボード、磁気装置や光装置などの記憶装置、モデム、A/Dコンバータ、上記の測定モジュール1330などの各種モジュール)を有する汎用コンピュータとすることが出来る。ディスプレイ2320を作動させるためのソフトウェア命令(例えば上記種々の方法)は、例えば記憶媒体からメモリ2314へロードし、CPU2312によって実行することが出来る。従って、本発明のソフトウェア命令は、コンピュータで読むことの出来る媒体に保存することが出来る。

【0155】ディスプレイ2320は、画素インターフェイス2322と、複数の画素(画素構造300、500、または700)とから成る。画素インターフェイス2322は画素300、500、または700の駆動に必要な回路を含む。例えば、画素インターフェイス2322は、図1に示したようなマトリックス・アドレス・インターフェイスとすることが出来、また、オプションとして追加の上記の信号ライン/制御ラインを含むことが出来る。

【0156】従って、システム2300は、ラップトップコンピュータとして実施することが出来る。あるいは、ディスプレイコントローラ2310は、マイクロコントローラとして、または特定用途の集積回路(ASIC)として、またはハードウェアとソフトウェア命令との組合せとして、実施することが出来る。要するに、システム2300は、本発明を組込んだ大きなシステム内において実施することが出来る。

【0157】本発明を、NMOSトランジスタを使用するものとして説明したが、本発明は、関連電圧が逆転したPMOSトランジスタを使用しても実現可能である。

【0158】以上、本発明の種々の実施態様を本明細書に示しかつ詳細に説明したが、本発明の要旨を超えない限りにおいて多くの態様を取り得ることが出来る。

【0159】

【発明の効果】本発明のディスプレイは輝度の均一性が大幅に改善されており、その工業的価値は高い。

【図面の簡単な説明】

【図1】マトリックスアドレスインターフェイスのブロック図

【図2】従来技術のアクティブマトリックスLED画素構造の略図

【図3】本発明のアクティブマトリックスLED画素構造の略図

【図4】図3のアクティブマトリックスLED画素構造のためのタイミング図

【図5】本発明の代替実施態様のアクティブマトリックスLED画素構造の略図

【図6】図5のアクティブマトリックスLED画素構造のためのタイミング図

【図7】本発明の代替実施態様のアクティブマトリックスLED画素構造の略図

【図8】図7のアクティブマトリックスLED画素構造のためのタイミング図

【図9】本発明の代替実施態様のアクティブマトリックスLED画素構造の略図

【図10】本発明の代替実施態様のアクティブマトリックスLED画素構造の略図

【図11】図10のアクティブマトリックスLED画素構造のためのタイミング図

【図12】画素アレイを相互接続して画素ブロックとした略図

【図13】ディスプレイとディスプレイコントローラとの相互接続の略図

【図14】全画素のパラメータの測定によってディスプレイを初期化する方法のフローチャート

【図15】画素電圧を表す入力データの補正方法のフローチャート

【図16】画素電流すなわち輝度を表す入力ビデオデータの補正方法のフローチャート

【図17】ビデオデータが画素電圧を表す場合、全画素のパラメータの測定によってディスプレイを初期化する方法のフローチャート

【図18】画素電圧を表す入力ビデオデータの補正方法のフローチャート

【図19】ビデオデータが画素電流を表す場合、全画素のパラメータの測定によってディスプレイを初期化する方法のフローチャート

【図20】画素電流すなわち輝度を表す入力ビデオデータの補正方法のフローチャート

【図21】ビデオデータがガンマ補正された輝度データを表す場合、全画素のパラメータの測定によってディスプレイを初期化する方法のフローチャート

【図22】ガンマ補正された輝度データで表された入力ビデオデータの補正方法のフローチャート

【図23】本発明による複数のアクティブマトリックスLED画素構造を有するディスプレイを使用したシステムのブロック図

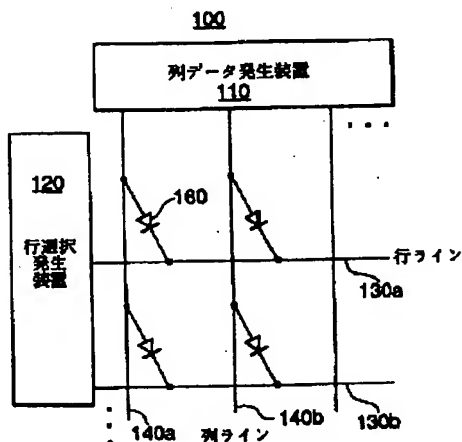
【符号の説明】

100:ディスプレイ



110:列データ発生装置  
 120:行データ発生装置  
 130:行ライン  
 160:表示要素(画素)  
 200:従来技術のアクティブマトリックスLED画素構造  
 300:本発明の画素構造  
 302:コンデンサ  
 304:LED(OLED)(光要素)  
 310:第1トランジスタ  
 320:第2トランジスタ  
 330:第3トランジスタ  
 340:第4トランジスタ  
 350:第5トランジスタ  
 360:データライン  
 370:選択ライン  
 380:オートゼロライン  
 382:前の行からのオートゼロライン  
 390:VDDライン  
 500:本発明の好ましい画素構造  
 510:第1トランジスタ  
 520:第2トランジスタ  
 530:第3トランジスタ  
 502:コンデンサ  
 540:ショットキダイオード  
 550:LED(OLED)(光要素)  
 570:選択ライン  
 560:データライン  
 580:オートゼロライン  
 590:点灯ライン  
 700:本発明の好ましい画素構造  
 702:コンデンサ  
 704:LED(OLED)(光要素)

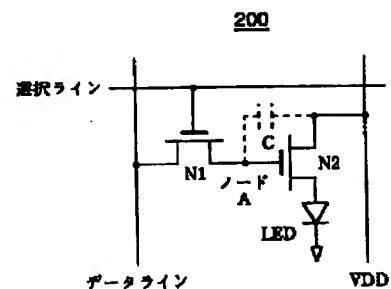
【図1】



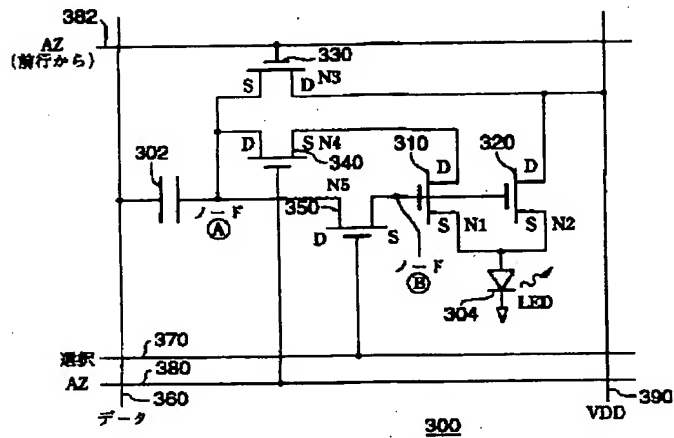
\* 710:第1トランジスタ  
 720:第2トランジスタ  
 730:第3トランジスタ  
 740:第4トランジスタ  
 750:第5トランジスタ  
 760:データライン  
 770:選択ライン  
 780:オートゼロライン  
 782:前の行からのオートゼロライン  
 10 790:VDDライン  
 900:本発明の好ましい画素構造  
 992:V<sub>precharge</sub>  
 950:第5トランジスタ  
 1000:本発明の画素構造  
 1010:データドライバ  
 1020:列トランジスタ  
 1200:画素ブロック  
 1210:検知ピン(VDD/SENSE)  
 1310:ディスプレイ  
 20 1320:ディスプレイコントローラ  
 1330:測定モジュール  
 1332:トランジスタP2  
 1334:電流検知回路  
 1350:VDDコントロールモジュール  
 1352:トランジスタP1  
 2300:システム  
 2310:ディスプレイコントローラ  
 2312:中央処理装置CPU  
 2314:メモリー  
 30 2316:I/O装置  
 2320:ディスプレイ  
 2322:画素インターフェイス

\*

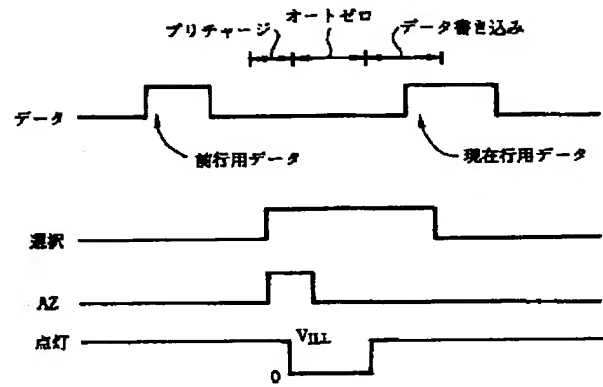
【図2】



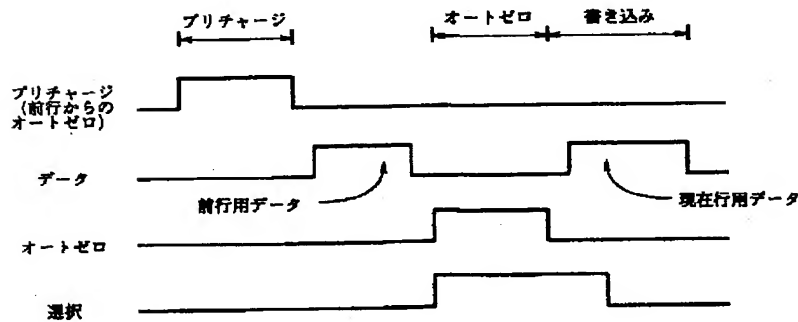
【図3】



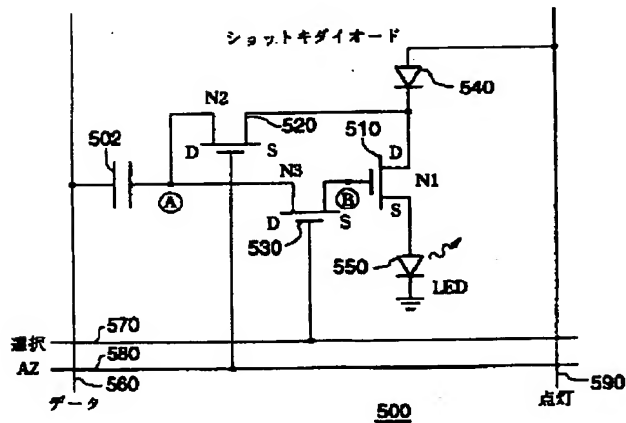
【図6】



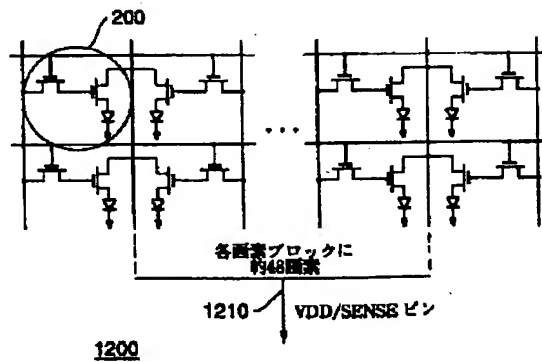
【図4】



【図5】

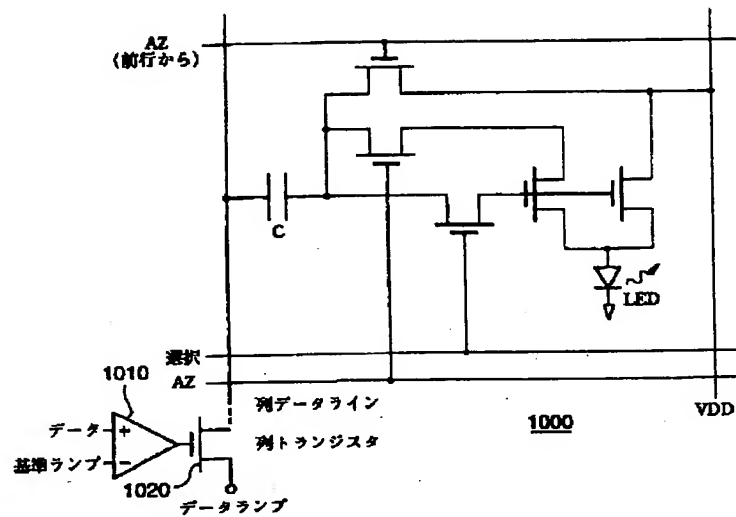


【図12】

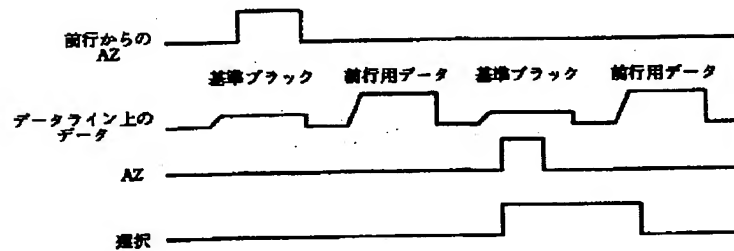




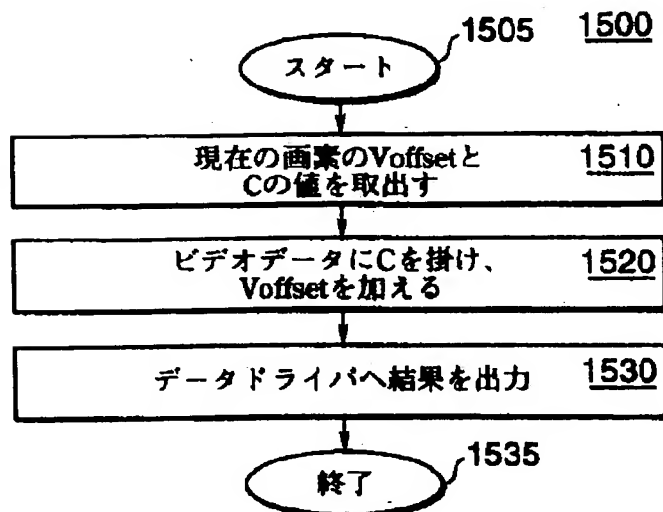
【図10】



【図11】

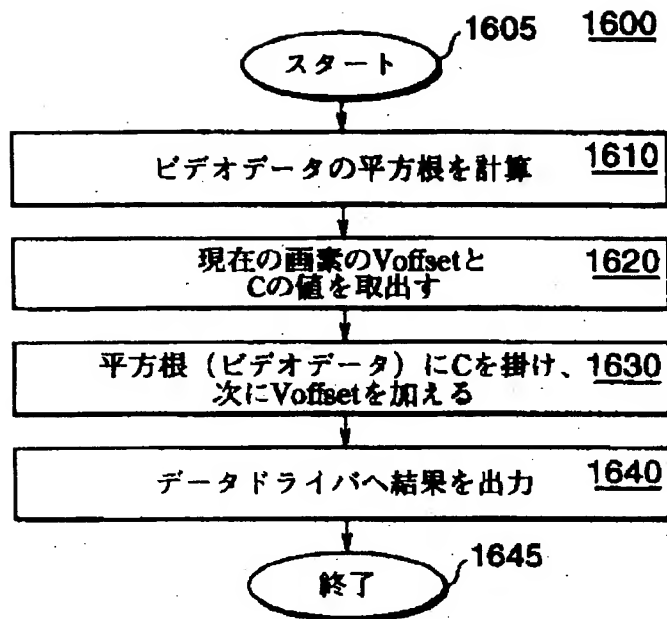


【図15】

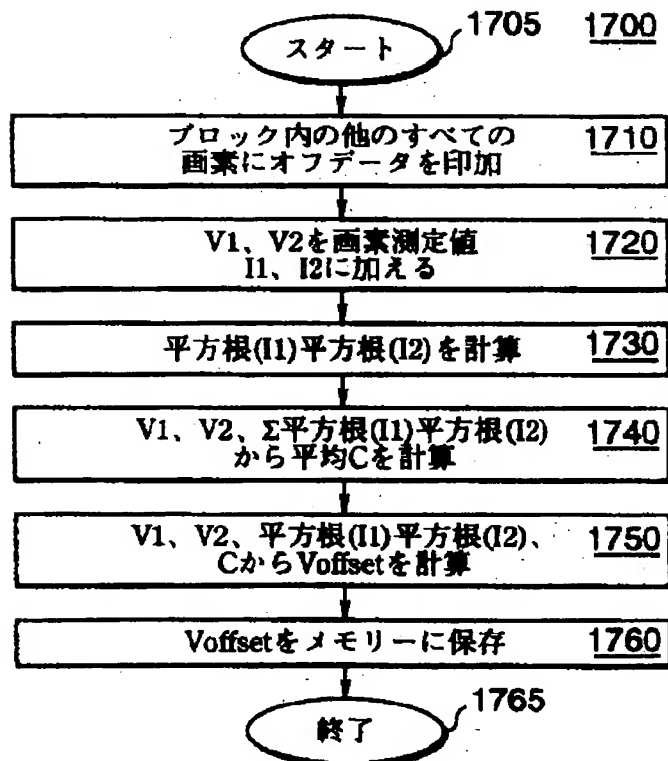




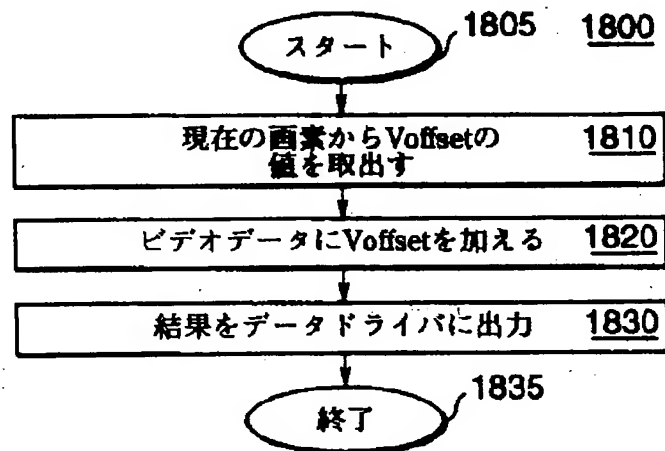
【図16】



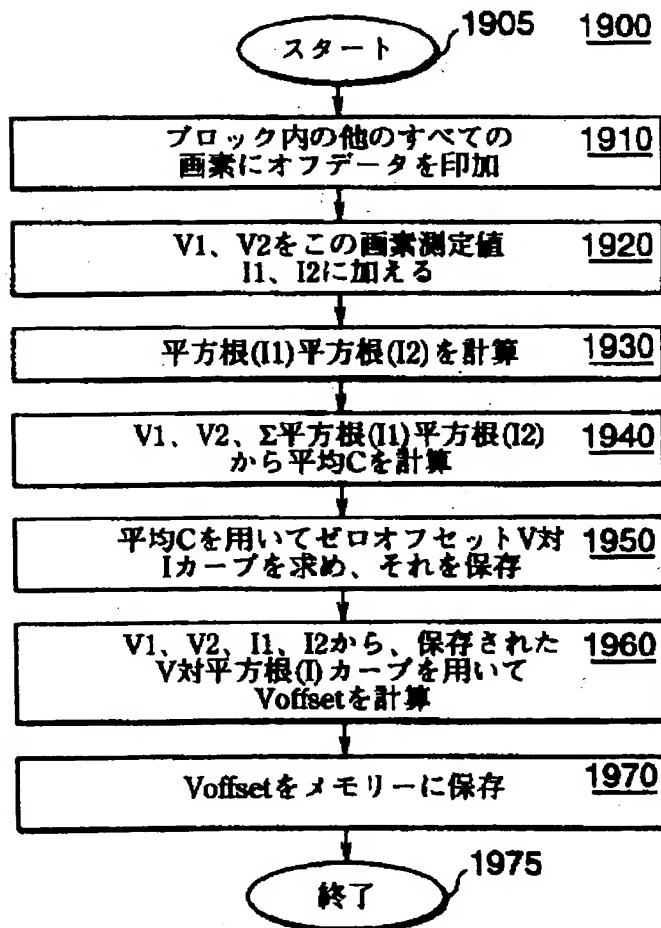
【図17】



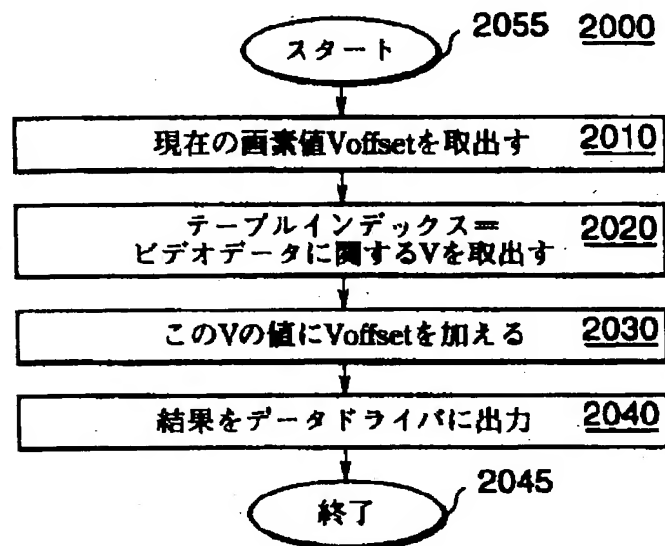
【図18】



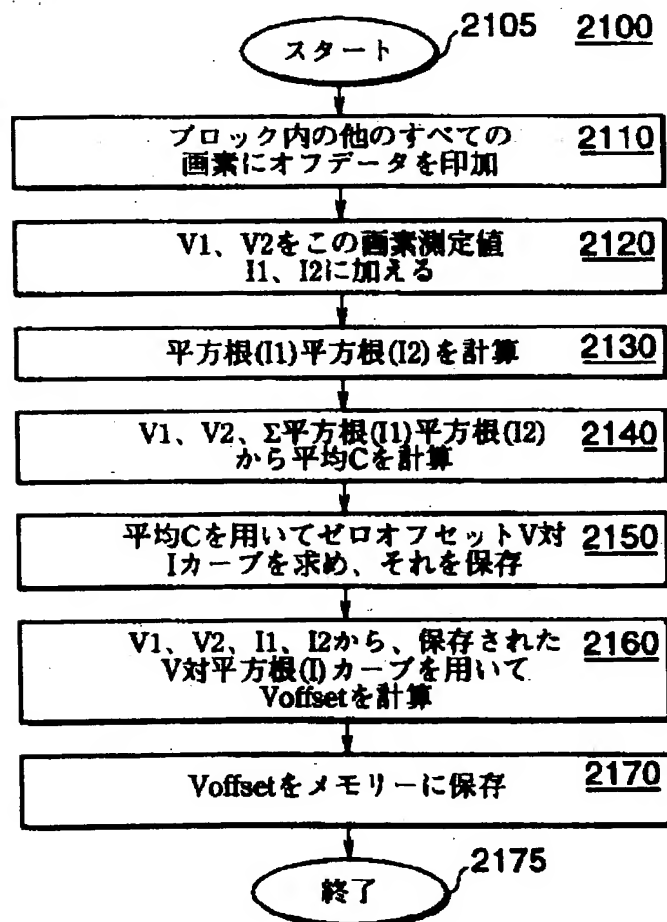
【図19】



【図20】

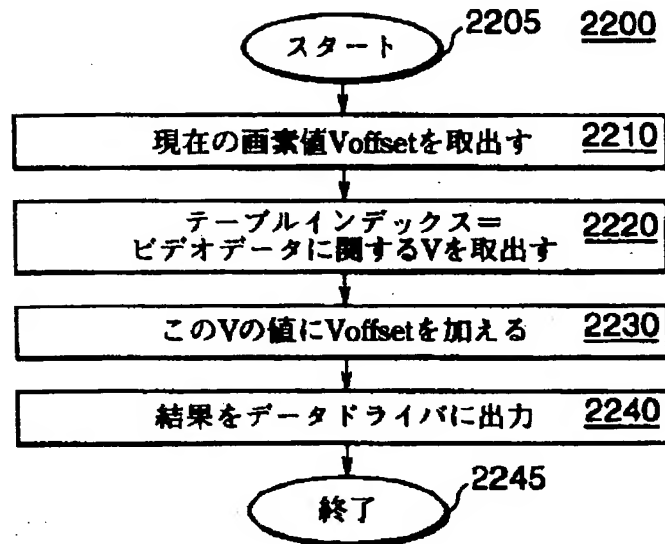


【図21】





【図22】



フロントページの続き

(51)Int.Cl.<sup>6</sup>

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【外国語明細書】

## ACTIVE MATRIX LIGHT EMITTING DIODE PIXEL STRUCTURE AND CONCOMITANT METHOD

This application claims the benefit of U.S. Provisional Application  
5 No. 60/060, 386 filed September 29, 1997, and U.S. Provisional Application  
No. 60/060, 387 filed September 29, 1997, which are herein incorporated by  
reference.

The invention relates to an active matrix light emitting diode pixel  
10 structure. More particularly, the invention relates to a pixel structure that  
improves brightness uniformity by reducing current nonuniformities in a  
light-emitting diode of the pixel structure and method of operating said  
active matrix light emitting diode pixel structure.

15

### BACKGROUND OF THE DISCLOSURE

Matrix displays are well known in the art, where pixels are  
illuminated using matrix addressing as illustrated in FIG. 1. A typical  
display 100 comprises a plurality of picture or display elements (pixels) 160  
that are arranged in rows and columns. The display incorporates a column  
20 data generator 110 and a row select generator 120. In operation, each row  
is sequentially activated via row line 130, where the corresponding pixels  
are activated using the corresponding column lines 140. In a passive matrix  
display, each row of pixels is illuminated sequentially one by one, whereas  
in an active matrix display, each row of pixels is first loaded with data  
25 sequentially. Namely, each row in the passive matrix display is only  
"active" for a fraction of the total frame time, whereas each row in the active  
matrix display can be set to be "active" for the entire total frame time.

With the proliferation in the use of portable displays, e.g., in a laptop  
computer, various display technologies have been employed, e.g., liquid  
30 crystal display (LCD) and light-emitting diode (LED) display. Generally, an  
important criticality in portable displays is the ability to conserve power,

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thereby extending the "on time" of a portable system that employs such display.

In a LCD, a backlight is on for the entire duration in which the display is in use. Namely, all pixels in a LCD are illuminated, where a  
5 "dark" pixel is achieved by causing a polarized layer to block the illumination through that pixel. In contrast, a LED display only illuminates those pixels that are activated, thereby conserving power by not having to illuminate dark pixels.

FIG. 2 illustrates a prior art active matrix LED pixel structure 200  
10 having two NMOS transistors N1 and N2. In such pixel structure, the data (a voltage) is initially stored in the capacitor C by activating transistor N1 and then activating "drive transistor" N2 to illuminate the LED. Although a display that employs the pixel structure 200 can reduce power consumption, such pixel structure exhibits nonuniformity in intensity level  
15 arising from several sources.

First, it has been observed that the brightness of the LED is proportional to the current passing through the LED. With use, the threshold voltage of the "drive transistor" N2 may drift, thereby causing a change in the current passing through the LED. This varying current  
20 contributes to the nonuniformity in the intensity of the display.

Second, another contribution to the nonuniformity in intensity of the display can be found in the manufacturing of the "drive transistor" N2. In some cases, the "drive transistor" N2 is manufactured from a material that is difficult to ensure initial threshold voltage uniformity of the transistors  
25 such that variations exist from pixel to pixel.

Third, LED electrical parameters may also exhibit nonuniformity. For example, it is expected that OLED (organic light-emitting diode) turn-on voltages may increase under bias-temperature stress conditions.

Therefore, a need exists in the art for a pixel structure and  
30 concomitant method that reduces current nonuniformities due to threshold voltage variations in a "drive transistor" of the pixel structure.

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### SUMMARY OF THE INVENTION

The present invention incorporates a LED (or an OLED) pixel structure and method that improve brightness uniformity by reducing current nonuniformities in a light-emitting diode of the pixel structure. In one embodiment, a pixel structure having five transistors is disclosed. In an alternate embodiment, a pixel structure having three transistors and a diode is disclosed. In yet another alternate embodiment, a different pixel structure having five transistors is disclosed. In yet another alternate embodiment, an additional line is provided to extend the autozeroing voltage range. Finally, an external measuring module and various external measuring methods are disclosed to measure pixel parameters that are then used to adjust input pixel data.

### BRIEF DESCRIPTION OF THE DRAWINGS

The teachings of the present invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawings, in which:

FIG. 1 depicts a block diagram of a matrix addressing interface;

FIG. 2 depicts a schematic diagram of a prior art active matrix LED pixel structure;

FIG. 3 depicts a schematic diagram of an active matrix LED pixel structure of the present invention;

FIG. 4 depicts a timing diagram for active matrix LED pixel structure of FIG. 3;

FIG. 5 depicts a schematic diagram of an alternate embodiment of an active matrix LED pixel structure of the present invention;

FIG. 6 depicts a timing diagram for active matrix LED pixel structure of FIG. 5;

FIG. 7 depicts a schematic diagram of an alternate embodiment of an active matrix LED pixel structure of the present invention;

FIG. 8 depicts a timing diagram for active matrix LED pixel structure of FIG. 7;

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FIG. 9 depicts a schematic diagram of an alternate embodiment of an active matrix LED pixel structure of the present invention;

FIG. 10 depicts a schematic diagram of an alternate embodiment of an active matrix LED pixel structure of the present invention;

5        FIG. 11 depicts a timing diagram for active matrix LED pixel structure of FIG. 10;

FIG. 12 illustrates a schematic diagram of an array of pixels interconnected into a pixel block;

FIG. 13 is a schematic diagram illustrating the interconnection  
10    between a display and a display controller;

FIG. 14 illustrates a flowchart of a method for initializing the display by measuring the parameters of all the pixels;

FIG. 15 illustrates a flowchart of a method for correcting input data representing pixel voltages;

15        FIG. 16 illustrates a flowchart of a method for correcting input video data representing pixel currents, i.e., luminances;

FIG. 17 illustrates a flowchart of a method for initializing the display by measuring the parameters of all the pixels where the video data represent pixel voltage;

20        FIG. 18 illustrates a flowchart of a method for correcting input video data representing pixel voltages;

FIG. 19 illustrates a flowchart of a method for initializing the display by measuring the parameters of all the pixels for the situation where the video data represents pixel currents;

25        FIG. 20 illustrates a flowchart of a method for correcting input video data represented in pixel currents, i.e., luminances;

FIG. 21 illustrates a flowchart of a method for initializing the display by measuring the parameters of all the pixels for the situation where the video data represents gamma-corrected luminance data;

30        FIG. 22 illustrates a flowchart of a method for correcting input video data represented in gamma-corrected luminance data; and

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FIG. 23 depicts a block diagram of a system employing a display having a plurality of active matrix LED pixel structures of the present invention.

To facilitate understanding, identical reference numerals have been  
5 used, where possible, to designate identical elements that are common to the figures.

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DETAILED DESCRIPTION

FIG. 3 depicts a schematic diagram of an active matrix LED pixel structure 300 of the present invention. In the preferred embodiment, the active matrix LED pixel structure is implemented using thin film transistors (TFTs), e.g., transistors manufactured using poly-silicon or amorphous silicon. Similarly, in the preferred embodiment, the active matrix LED pixel structure incorporates an organic light-emitting diode (OLED). Although the present pixel structure is implemented using thin film transistors and an organic light-emitting diode, it should be understood that the present invention can be implemented using other types of transistors and light emitting diodes.

The present pixel structure 300 provides a uniform current drive in the presence of a large transistor threshold voltage ( $V_t$ ) nonuniformity and OLED turn-on voltage nonuniformity. In other words, it is desirable to maintain a uniform current through the OLEDs, thereby ensuring uniformity in the intensity of the display.

Referring to FIG. 3, pixel structure 300 comprises five NMOS transistors N1 (310), N2 (320), N3 (330), N4 (340) and N5 (350), a capacitor 302 and a LED (OLED) (light element) 304 (light element). A Select line 370 is coupled to the gate of transistor 350. A Data line 360 is coupled to one terminal of the capacitor 302. An Autozero line 380 is coupled to the gate of transistor 340. A VDD line 390 is coupled to the drain of transistors 320 and 330. An Autozero line 382 from a previous row in the pixel array is coupled to the gate of transistor 330.

It should be noted that Autozero line 382 from a previous row can be implemented as a second Select line. Namely, the timing of the present pixel is such that the Autozero line 382 from a previous row can be exploited without the need of a second Select line, thereby reducing complexity and cost of the present pixel.

One terminal of the capacitor 302 is coupled (at node A) to the source of transistor 330 and to the drain of transistors 340 and 350. The source of

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transistor 350 is coupled (at node B) to the gate of transistors 310 and 320. The drain of transistor 310 is coupled to the source of transistor 340. Finally, the source of transistors 310 and 320 are coupled to one terminal of the LED 304.

5 As discussed above, driving an organic LED display is challenging in light of the various nonuniformities. The present invention is an architecture for an organic LED display that addresses these criticalities. Namely, each LED pixel is driven in a manner that is insensitive to variations in the LED turn-on voltage, as well as to variations in the TFT  
10 threshold voltages. Namely, the present pixel is able to determine an offset voltage parameter using an autozeroing method that is used to account for these variations in the LED turn-on voltage, and the TFT threshold voltages.

Furthermore, data is provided to each pixel as a data voltage in a  
15 manner that is very similar to that used in conventional active-matrix liquid crystal displays. As a result, the present display architecture can be employed with conventional column and row scanners, either external or integrated on the display plate.

The present pixel uses five (5) TFTs and one capacitor, and the LED.  
20 It should be noted that TFTs are connected to the anode of the LED, and not the cathode, which is required by the fact that ITO is the hole emitter in conventional organic LED. Thus, the LED is coupled to the source of a TFT, and not the drain. Each display column has 2 row lines (the auto-zero line and the select line), and 1 1/2 column lines (the data line and the +Vdd line,  
25 which is shared by neighboring columns). The waveforms on each line are also shown in FIG. 4. The operation of the pixel 300 is described below in three phases or stages.

The first phase is a precharge phase. A positive pulse on the auto-zero (AZ) line of the previous row 382 turns "on" transistor 330 and  
30 precharges node A of the pixel up to Vdd, e.g., +10 volts. Then the Data line changes from its baseline value to write data into the pixel of the previous



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row, and returns to its baseline. This has no net effect on the pixel under consideration.

The second phase is an auto-zero phase. The AZ and SELECT lines for the present row go high, turning "on" transistors 340 and 350 and  
5 causing the gate of transistor N1 310 to drop, self-biasing to a turn-on voltage that permits a very small trickle of current to flow through the LED. In this phase the sum of the turn-on voltage of the LED and the threshold voltage of N1 are stored on the gate of N1. Since N1 and N2 can be placed very close together, their initial threshold voltages will be very similar. In  
10 addition, these two transistors should have the same gate to source voltage,  $V_{gs}$ . Since a TFT threshold drift depends only on  $V_{gs}$  over the life of the TFT, it can be assumed that the threshold voltages of these devices will track over the life of the TFT. Therefore, the threshold voltage of N2 is also stored on its gate. After auto-zeroing is complete, the Autozero line returns  
15 low, while Select line stays high.

The third phase is a data writing phase. The data is applied as a voltage above the baseline voltage on the Data line, and is written into the pixel through the capacitor. Then, the Select line returns low, and the sum of the data voltage, plus the LED turn-on voltage, plus N2's threshold  
20 voltage, is stored at node B for the rest of the frame. It should be noted that a capacitor from node B to  $+V_{dd}$  can be employed in order to protect the stored voltage from leaking away.

In sum, during the auto-zero phase, the LED's turn-on voltage, as well as N2's threshold voltage, are "measured" and stored at node B using a  
25 trickle current. This auto-zero phase is essentially a current-drive mode of operation, where the drive current is very small. It is only after the auto-zero phase, in the writing phase, that the voltage on the LED is incremented above turn-on using the applied data voltage. Thus, the present invention can be referred to as having a "hybrid drive," rather than  
30 a voltage drive or current drive. The hybrid drive method combines the advantages of voltage drive and current drive, without the disadvantages of either. Variations in the turn-on voltage of the LED and the threshold

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voltage of the TFT are corrected, just as in current drive. At the same time, all lines on the display are driven by voltages, and can therefore be driven fast.

It should be noted that the data voltage increment applied to the  
5 Data line 360 does not appear directly across the LED 304, but is split between  $V_{gs}$  of N2 320 and the LED. This simply means that there is a nonlinear mapping from the data voltage to the LED voltage. This mapping, combined with the nonlinear mapping from LED voltage to LED current, yields the overall transfer function from data voltage to LED  
10 current, which is monotonic, and, as noted above, is stable over the life of the display.

An advantage of the present pixel architecture 300 is that the transistors in the pixel whose threshold shifts are uncorrected (N3, N4, and N5) are turned on for only one row-time per frame, and therefore have a  
15 very low duty-cycle and are not expected to shift appreciably. Additionally, N2 is the only transistor in the LED's current path. Additional transistors connected in series on this path may degrade display efficiency or may create problems due to uncorrected TFT threshold shifts, and, if shared by all pixels on a column, may introduce significant vertical crosstalk.

20 Select and Autozero (AZ) pulses are generated by row scanners. The column data is applied on top of a fixed (and arbitrary) baseline voltage in the time-slot between AZ pulses. The falling edge of Select signal occurs while data is valid on the Data line. Various external and integrated column-scanner designs, either of the direct-sample or chopped-ramp type,  
25 can produce data with this timing.

The above pixel architecture permits large direct-view displays to be built using organic LEDs. Of course, the present pixel structure is also applicable to any display technology that uses display elements requiring drive current, particularly, when the display elements or the TFTs have  
30 turn-on voltages that shift or are nonuniform.

FIG. 5 depicts a schematic diagram of an alternate embodiment of an active matrix LED pixel structure 500 of the present invention. The pixel

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structure 500 is similar to the pixel structure 300 of FIG. 3, where a Schottky diode is now employed in lieu of two transistors.

One potential disadvantage of the pixel structure 300 is the use of five transistors per pixel. Namely, using so many transistors in each pixel  
5 may impact the pixel's fill-factor (assuming bottom-side emission through the active plate), and also its yield. As such, the pixel structure 300 employs a single Schottky diode in each pixel that reduces the number of transistors from five to three transistors, while performing the same functions as previously described.

10 Referring to FIG. 5, pixel structure 500 comprises three NMOS transistors N1 (510), N2 (520), N3 (530), a capacitor 502, a Schottky diode 540 and a LED (OLED) 550 (light element). A Select line 570 is coupled to the gate of transistor 530. A Data line 560 is coupled to one terminal of the capacitor 502. An Autozero line 580 is coupled to the gate of transistor 520.  
15 An Illuminate (similar to a VDD line) line 590 is coupled to one terminal of the Schottky diode 540.

One terminal of the capacitor 502 is coupled (at node A) to the drain of transistors 520 and 530. The source of transistor 530 is coupled (at node B) to the gate of transistor 510. The drain of transistor 510 is coupled to the  
20 source of transistor 520, and one terminal of the Schottky diode 540.

The pixel structure 500 also has three phases of operation: a precharge phase, an autozero phase, and a data writing phase as discussed below. All of the Illuminate lines are connected together at the periphery of the display, and before the precharge phase begins, the Illuminate lines are  
25 held at a positive voltage  $V_{ILL}$ , which is approximately +15V. For the purpose of the following discussion, a row under consideration is referred to as "row i". The waveforms on each line are also shown in FIG. 6.

The first phase is a precharge phase. Precharge is initiated when the Autozero (AZ) line turns on transistor N2, and the Select line turns on  
30 transistor N3. This phase is performed while the Data line is at a reset level. The voltage at Nodes A and B rises to the same voltage as the drain of transistor N1, which is a diode drop below  $V_{ILL}$ .

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The second phase is an autozero phase. Next, the Illuminate line drops to ground. During this phase, all pixels on the array will briefly darken. Autozeroing of N1 now begins with the Schottky diode 540 causing the drain of transistor N1 to be isolated from the grounded Illuminate line.

5 When Node B has reached a voltage approximately equal to the threshold voltage of the transistor N1 plus the turn-on voltage of the LED 550, the AZ line is used to turn transistor N2 "off", and the Illuminate line is restored to  $V_{LL}$ . All pixels in unselected rows light up again.

The third phase is a data writing phase. Next, the data for row  $i$  is loaded onto the data line. The voltage rise at Nodes A and B will equal the difference between the Data line's reset voltage level and the data voltage level. Thus, variations in the threshold voltage of transistor N1 and the LED's turn-on voltage will be compensated. After the voltage at Node B has settled, the Select line for row  $i$  is used to turn off transistor N3, and the  
15 Data line is reset. The proper data voltage is now stored on the pixel until the next frame.

Thus, a three-transistor pixel for OLED displays has been described, that possesses the advantages described previously for the 5-transistor pixel 300, but requires fewer transistors. An additional advantage is that the 5-  
20 transistor pixel employs separate transistors for autozeroing and driving the LED. Proper operation of pixel 300 requires that these two transistors have matching initial thresholds that would drift over life in the same way. Recent experimental data suggest that TFTs with different drain voltages (as these two transistors have) may not drift in the same way. Thus, pixel  
25 500 performs autozeroing on the same transistor that drives the LED, such that proper autozeroing is guaranteed.

FIG. 7 depicts a schematic diagram of an alternate embodiment of an active matrix LED pixel structure 700 of the present invention. The pixel structure 700 is similar to the pixel structure 300 of FIG. 3, with the  
30 exception that pixel structure 700 may generate a more precise autozero voltage.

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Namely, referring to FIG. 3, the autozeroing arises from the fact that each precharge cycle, as shown in FIG. 3, injects a large positive charge  $Q_{pc}$  onto Node A of the pixel 300. During the precharge phase, nearly all of the capacitance on Node A is from capacitor  $C_{data}$ , such that the charge injected  
 5 onto Node A is:

$$Q_{pc} \equiv C_{data}(V_{00} - V_A) \quad (1)$$

where  $V_A$  is the voltage that was on Node A before the precharge phase  
 10 began.  $V_A$  depends on the threshold voltage of N3 330 and the turn-on voltage of the LED 304, as well as the previous data applied to the pixel 300. Since  $C_{data}$  is a large capacitance (approx. 1 pF),  $Q_{pc}$  is also relatively large, on the order of ten picocoulombs.

When the pixel 300 is at a stable autozero level,  $Q_{pc}$  flows through N1  
 15 310 and the LED 304 during the autozero phase. Since the autozero interval is short (approximately 10  $\mu$ sec.), N1 may be left with a gate-to-source autozero voltage higher than its threshold voltage, and similarly the LED autozeroes above its turn-on voltage. Thus, the autozeroing process may not produce a true zero-current autozero voltage at Nodes A and B, but  
 20 instead, an approximation of a zero-current autozero voltage.

It should be noted that it is not necessary to produce a true zero-current autozero voltage, corresponding to exactly zero current through N1 and the LED. The desirable goal is to obtain an autozero voltage that permits a small trickle of current (approximately ten nanoamps) to flow  
 25 through N1 310 and the LED 304. Since the autozero interval is approximately 10  $\mu$ sec, then  $Q_{pc}$  should be on the order of 0.1 picocoulomb. As noted above,  $Q_{pc}$  is approximately 10 picocoulombs.

The effect of such a large  $Q_{pc}$  is that the pixel's stable autozero voltage may well be above the sum of the threshold and turn-on voltages.  
 30 This condition by itself is not a problem, if the excess autozero voltages were

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uniform across the display. Namely, the effect can be addressed by offsetting all the data voltages accordingly.

However, a potential difficulty may arise if  $Q_{pc}$  is not only large, but also depends on the previous data voltage, and on the autozero voltage itself. If this condition develops in the display, then not only will all pixels have large excess autozero voltages, but also the magnitude of the excess voltage may vary from pixel to pixel. In effect, the autozeroing of pixel 300 may not produce a uniform display under such a condition.

To address this criticality, the pixel structure 700 is capable of reducing the precharge  $Q_{pc}$  to a very small value. Additionally, a "variable precharge" method is disclosed, that permits  $Q_{pc}$  to vary, depending on the amount of charge that is actually needed for autozeroing. In brief, if the current autozero voltage is too low,  $Q_{pc}$  assumes its maximum value of about 0.1 picocoulomb in order to raise the autozero voltage toward its desired value. However, if the current autozero voltage is too high, then  $Q_{pc}$  is essentially zero, allowing the autozero voltage to drop quickly.

Referring to FIG. 7, pixel structure 700 comprises five NMOS transistors N1 (710), N2 (720), N3 (730), N4 (740), N5 (750), a capacitor 702, and a LED (OLED) 704 (light element). A Select line 770 is coupled to the gate of transistor 710. A Data line 760 is coupled to one terminal of the capacitor 702. An Autozero line 780 is coupled to the gate of transistor 740. A VDD line 790 is coupled to the drain of transistors 720 and 750. An Autozero line 782 from a previous row in the pixel array is coupled to the gate of transistor 750.

It should be noted that Autozero line 782 from a previous row can be implemented as a second Select line. Namely, the timing of the present pixel is such that the Autozero line 782 from a previous row can be exploited without the need of a second Select line, thereby reducing complexity and cost of the present pixel.

One terminal of the capacitor 702 is coupled (at node A) to the drain of transistor 710. The source of transistor 710 is coupled (at node B) to the gate of transistors 720 and 730 and is coupled to the source of transistor

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740. The drain of transistor 740 is coupled (at node C) to the source of transistor 750, and to the drain of transistor 730. Finally, the source of transistors 730 and 720 are coupled to one terminal of the LED 704.

More specifically, the pixel 700 is similar to the pixel 300, except that  
5 the precharge voltage is now applied to Node C, which is the drain of transistor N3 730. In addition, there are also some timing changes as shown in FIG. 8. The operation of the pixel 700 is again described below in three phases or stages.

The first phase is a precharge phase that occurs during the previous  
10 line time, i.e., before data is applied to the previous row's pixels. A positive pulse on the Select line turns "on" N1, thereby shorting Nodes A and B together, which returns the pixel 700 to the state it was in after the last autozero phase. Namely, the pixel is returned to a data-independent voltage that is the pixel's most recent estimate of its proper autozero  
15 voltage. While transistor N1 is "on", a positive pulse on the Autozero line 782 from a previous row line turns "on" transistor N5, thereby precharging Node C to  $V_{dd}$ . In turn, transistors N1 and N5 are turned "off".

The relative timing of turning transistors N1 and N5 "on" and "off" is not very important, except that transistor n1 must be "on" before transistor  
20 N5 is turned "off". Otherwise, transistor N3 may still be turned "on" in response to the old data voltage, and the charge injected onto Node C may inadvertently drain away through transistor N3.

After the precharge phase, the charge  $Q_{pc}$  is stored at Node C on the gate-to-source/drain capacitances of transistors N3, N4 and N5. Since these  
25 capacitances add up to a very small capacitance (about 10 fF), and the precharge interval raises Node C about 10V,  $Q_{pc}$  is initially approximately 0.1 picocoulombs. However, this charge will drain from Node C to varying degrees prior to the autozero phase, depending on how well the previous autozero voltage approximates the true autozero voltage. Thus, it is more  
30 accurate to indicate that  $Q_{pc} \leq 0.1$  picocoulomb, depending on how much charge is needed for autozeroing. This is the variable precharge feature. If the last autozero voltage is too low, N3 is nonconducting after the precharge

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phase, and  $Q_{pc}$  should stay at its maximum value, raising the autozero voltage toward its desired level during the autozero phase. If the last autozero voltage is too high, N3 is conducting, and  $Q_{pc}$  will drain off by the time the autozero phase occurs, allowing the autozero voltage to drop quickly.

Although the relative timing for transistors N1 and N5 is not critical, the preferred timing is shown in FIG. 8. The two transistors N1 and N5 turn "on" at the same time in order to minimize the time required for precharge. N1 turns "off" before N5 such that the (intentional) draining of  $Q_{pc}$  from Node C is in response to a Node B voltage that has been capacitively pushed down by N1 turning "off". This ensures that the draining of  $Q_{pc}$  from Node C is in response to a Node B voltage that is the same as when zero data is applied to the pixel.

In sum, the pixel 700 when compared to the pixel 300, provides a means of precharging the pixel that allows a more effective autozeroing. Specifically, the autozeroing of pixel 700 is more accurate, faster, and data independent. Computer simulations have verified that the pixel 700 autozeroes well and is able to maintain a nearly constant OLED current vs. data voltage characteristic over an operational lifetime of 10,000 hours.

FIG. 9 depicts a schematic diagram of an alternate embodiment of an active matrix LED pixel structure 900 of the present invention. The pixel structure 900 is similar to the pixel structure 700 of FIG. 7, with the exception of having an additional  $V_{precharge}$  line 992, that permits the range of autozero voltages to be extended without raising the LED supply voltage  $V_{dd}$ . This additional modification of the pixel extends the life and efficiency of the pixel.

It should be noted that the above described pixels (200, 300, 700) have the limitation that the autozero voltage cannot exceed  $V_{dd}$ , since this is the precharge voltage. However, as the threshold voltages of transistors N2 and N3 drift over the life of the transistor, a point is reached where an autozero voltage higher than  $V_{dd}$  is required in order to compensate for drift in the TFT threshold voltage and in the OLED turn-on voltage. Since the



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autozero voltage cannot reach higher voltages, display uniformity will quickly degrade, signaling the end of the useful life of the display. Raising  $V_{dd}$  will permit higher autozero voltages to be achieved, but at the expense of power efficiency, since  $V_{dd}$  is also the OLED drive supply.

5 Furthermore, the range of autozero voltages will be restricted even further if, in order to improve power efficiency,  $V_{dd}$  is reduced to operate transistor N2 in the linear region. (Of course, this will require N2 to be made larger than if it was operated in saturation.) In this case, the operating lifetime will be quite short, since after a short period of operation,  
10 the autozero voltage will need to reach a level higher than  $V_{dd}$ .

Referring to FIG. 9, an optional modification is incorporated into the pixel 700 that removes restrictions on the autozero voltage, thereby permitting it to be extended to well above  $V_{dd}$ . The pixel 900 is identical to the pixel 700 with the exception of an additional column line 992, that is  
15 coupled to the drain of transistor 950.

The column line 992 is added to the array to carry a DC voltage  $V_{precharge}$  to all the pixels. All of these column lines are connected together at the edge of the display. By raising  $V_{precharge}$  to a level higher than  $V_{dd}$ , the pixel 900 can precharge and autozero to a voltage higher than  $V_{dd}$ . A high  
20 value of  $V_{precharge}$  will have very little effect on display efficiency.

It should be noted that each  $V_{precharge}$  line 992 can be shared by neighboring columns of pixels. The  $V_{precharge}$  lines can also run as row lines, shared by neighboring rows.

In sum, a modification of the above OLED pixels is disclosed where  
25 an additional voltage line is provided to extend the range of the autozero voltages beyond  $V_{dd}$ . This allows the OLED drive transistor to operate at as low a voltage as needed for power efficiency, possibly even in the linear region, without restricting the range of autozero voltages. Thus, long operating lifetime and high efficiency can be obtained. Finally, although  
30 the present modification is described with respect to pixel 700, it should be understood that this optional modification can be employed with other

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autozeroing pixel structures, including but not limited to, pixels 200 and 300 as discussed above.

Although the above pixel structures are designed for an OLED display in such a manner that transistor threshold voltage variations and  
5 OLED turn-on voltage variations in the pixel can be compensated, these pixel structures are not designed to address nonuniformity that is generated external to the pixel. It was pointed out that the pixel could be used with conventional column driver circuits, either external to the display plate or integrated on the display.

10 Unfortunately, integrated data drivers are typically not as accurate as external drivers. While commercially available external drivers can achieve  $\pm 12$  mV accuracy, it has proven difficult to achieve accuracy better than  $\pm 50$  mV using integrated drivers. The particular type of error produced by integrated drivers is primarily offset error, i.e., it is a data-  
15 independent DC level that adds to all data voltages. The offset error is nonuniform, i.e., the value of the DC level varies from one data driver to the next. Liquid crystal displays tend to be forgiving of offset errors because the liquid crystal is driven with opposite polarity data in successive frames, such that in one frame the offset error causes the liquid crystal to be slightly  
20 too dark, and in the next frame too light, but the average is nearly correct and the alternating errors are not noticeable to the eye. However, an OLED pixel is driven with unipolar data. Therefore, the bipolar cancellation of offset errors does not occur, and serious nonuniformity problems may result when integrated scanners are used.

25 FIG. 10 depicts a schematic diagram of an active matrix LED pixel structure 300 of the present invention coupled to a data driver 1010 via a column transistor 1020. The present invention describes a method for canceling offset errors in integrated data scanners for OLED displays. Namely, the present method is designed to operate with any pixel in which  
30 the pixel is capacitively coupled to a data line, and has an autozero phase, e.g., pixels 200, 300, 500, and 700 as discussed above.

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Referring to FIG. 10, the pixel 300 as described above is coupled to a Data line that provides the pixel with an analog level to establish the brightness of the OLED element. In FIG. 10, the Data line is driven by a data driver that uses the chopped ramp technique to set the voltage on the Data line. Various sources of error exist in this approach that may give rise to offset errors on the Data line. For example, the time at which the voltage comparator switches can vary depending on the comparator's maximum slew rate. It has also been observed experimentally that the maximum slew rate can be highly variable. The offset error will affect the voltage stored in the pixel. Since it is nonuniform, the offset error will also lead to brightness variations across the display.

In the present invention, the period during which the pixel autozeros to cancel its own internal threshold error is also used to calibrate out the data scanner's offset error. The waveforms of the various lines is shown in FIG. 11.

Namely, this is accomplished by setting a reference black level on the Data line using the same column driver that will apply the actual data voltage. This reference black level, applied during the pixel's autozero phase, is set on the Data line in exactly the same manner that the actual data voltage will be set: the data ramp is chopped at a time determined by the voltage comparator. Thus, the voltage across capacitor C of the pixel is determined by the difference between the pixel's turn-on voltage and the combined black level plus the offset error voltage. The reference black level is maintained for the entire autozero phase. When the actual data is applied to the pixel, the data scanner offset error is now canceled by the stored voltage on the pixel capacitor.

This technique can be applied not only to integrated scanners that use a chopped ramp, but also to scanners using direct sampling onto the columns. In the case of direct sampling, the error arises from the nonuniform capacitive feedthrough of the gate signal onto the Data line when the (large) column transistor turns off. Variations in the threshold voltage of this transistor produce a nonuniform offset error, just like the

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nonuniform offset error produced by the chopped ramp data scanners.

Thus, it can be corrected in the same manner. A black reference voltage is written onto the columns during the pixel's autozero phase. Since all of the pixels in a row autozero at the same time, this black level is  
5 written onto all of the data columns simultaneously at the beginning of the line time. The black level is maintained for the entire autozero phase. As in the case of the chopped-ramp scanner, when the actual data is applied to the pixel, the offset error will be canceled by the voltage stored on the pixel capacitor. However, it seems likely that the time overhead required to  
10 perform offset error correction is smaller using the direct-sampling technique than with the chopped ramp technique.

The present method for correcting data driver errors should permit organic LED displays to be built with much better brightness uniformity than would otherwise be possible. Using the method described here,  
15 together with any of the above autozeroing pixels, brightness uniformity of 8-bits should be achievable, with no visible uniformity degradation over the lifetime of the display.

Although the above disclosure describes a plurality of pixel structures that can be employed to account for nonuniformity in the intensity of a  
20 display, an alternative approach is to compensate such nonuniformity by using external means. More specifically, the disclosure below describes an external calibration circuit and method to account for nonuniformity in the intensity of a display. In brief, the non-uniformity is measured and stored for all the pixels such that the data (e.g., data voltages) can be calibrated  
25 using the measured non-uniformity.

As such, although the conventional pixel structure of FIG. 2 is used in the following discussion, it should be understood that the present external calibration circuit and method can be employed with other pixel structures, including but not limited to, the pixels 300, 500, and 700 as described above.  
30 However, if the non-uniformity is addressed by the present external calibration circuit and method, then a more simplified pixel structure can be employed in the display, thereby increasing display yield and fill-factor.

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FIG. 12 illustrates a schematic diagram of an array of pixels 200 interconnected into a pixel block 1200. Referring to FIG. 2, in operation, data is written into the pixel array in the manner commonly used with active matrix displays. Namely, a row of pixels is selected by driving the  
5 Select line high, thereby turning on access transistor N1. Data is written into the pixels in this row by applying data voltages to the Data lines. After the voltage at node A has settled, the row is deselected by driving the Select line low. The data voltage is stored at node A until this row is selected again on the next frame. There may be some charge leakage from node A  
10 during the time that N1 is turned off, and a storage capacitor may be required at node A to prevent an unacceptable level of voltage decay. The dotted lines illustrate how a capacitor can be connected to address the voltage decay. However, it is possible that there is sufficient capacitance associated with the gate of N2 to render such additional capacitance  
15 unnecessary.

It should be noted that the luminance  $L$  of an OLED is approximately proportional to its current  $I$ , with the constant of proportionality being fairly stable and uniform across the display. Therefore, the display will be visually uniform if well-defined OLED currents are produced.

20 However, what is programmed into the pixel is not the OLED current, but rather the gate voltage on N2. It is expected that TFT threshold voltages and transconductances will exhibit some initial nonuniformity across a display, as will the OLED electrical parameters. Furthermore, it is well known that TFT threshold voltages increase under  
25 bias-temperature stress conditions, as do OLED turn-on voltages. Thus, these parameters are expected to be initially nonuniform, and to vary over the life of the pixel in a manner that depends on the individual bias history of each pixel. Programming the gate voltage of N2 without compensating for the variations of these parameters will yield a display that is initially  
30 nonuniform, with increasing nonuniformity over the life of the display.

The present invention describes a method for correcting the data voltage applied to the gate of N2 in such a way that variations in the TFT

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and OLED electrical parameters are compensated, thereby permitting well-defined OLED currents to be produced in the pixel array.

FIGs. 2 and 12 illustrate a pixel array having VDD supply lines that are disposed parallel to the Data lines. (In alternative embodiments, the VDD lines may run parallel to the Select lines.) As such, each VDD line can be shared by two or more neighboring columns of pixels to reduce the number of VDD lines. Figure 12 illustrates the VDD lines as being tied together into blocks on the periphery of the display. Each pixel block 1200 may contain as few as one VDD line, or as many as the total number of VDD lines on the display. However, in the preferred embodiment, each pixel block 1200 contain about 24 VDD lines, i.e., about 48 pixel columns.

FIG. 13 is a schematic diagram illustrating the interconnection between a display 1310 and a display controller 1320. The display 1310 comprises a plurality of pixel blocks 1200. The display controller 1320 comprises a VDD control module 1350, a measurement module 1330 and various I/O devices 1340 such as A/D converters and a memory for storing pixel parameters.

Each pixel block is coupled to a sensing pin (VDD/SENSE) 1210 at the edge of the display, as shown in FIGs. 12 and 13. During normal display operation, the sensing pins 1210 are switched to an external  $V_{dd}$  supply, e.g., between 10-15V, thereby supplying current to the display for illuminating the OLED elements. More specifically, each VDD/SENSE pin 1210 is associated with a pair of p-channel transistors P1 (1352) and P2 (1332) and a current sensing circuit 1334 in the display controller 1320. During normal operation, an ILLUMINATE signal from the display controller activates P1 to connect a VDD/SENSE pin to the  $V_{dd}$  supply. In a typical implementation, the current through P1 is expected to be approximately 1 mA per column.

In order to compensate for variations in the TFT and OLED parameters, the external current sensing circuits 1334 are activated via a MEASURE signal to collect information about each pixel's parameters during a special measurement cycle. The collected information is used to

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calculate or adjust the appropriate data voltages for establishing the desired OLED currents during normal display operation.

More specifically, during a given pixel's measurement cycle, all other pixels in the pixel block are tuned off by loading these pixels with low data  
5 voltages (e.g., zero volts or less), thereby ensuring negligible current draw from the "off" pixels. In turn, the current drawn by the pixel of interest is measured in response to one or more applied data voltages. During each measurement cycle, the data pattern (i.e., consisting of all pixels in a block turned "off" except for one pixel turned "on") is loaded into the pixels in the  
10 normal way, with data applied to the DATA lines by data driver circuits, and rows being selected one by one. Thus, since the display is partitioned into a plurality of pixel blocks, a plurality of pixels can be measured by turning on at least one pixel in each pixel block simultaneously.

The current drawn by the pixel of interest in each pixel block is  
15 measured externally by driving the ILLUMINATE and MEASURE lines to levels that disconnect the VDD/SENSE pin 1210 from VDD source and connect the sensing pin to the input of a current-sensing circuit 1334 through P2, where the current drawn by the pixel of interest is measured. The pixel current is expected to be in the range of 1-10  $\mu$ A. The current-  
20 sensing circuit 1334 is shown as a transimpedance amplifier in FIG. 13, but other embodiments of current-sensing circuit can be implemented. In the present invention, the amplifier generates a voltage at the output that is proportional to the current at the input. This measured information is then collected by I/O devices 1340 where the information is converted into digital  
25 form and then stored for calibrating data voltages. The resistor in the current-sensing circuit 1334 is approximately one Megohm.

Although multiple current-sensing circuits 1334 are illustrated with a one to one correspondence with the pixel blocks, fewer current-sensing circuits can be employed through the use of a multiplexer (not shown).  
30 Namely, multiple VDD/SENSE pins are multiplexed to a single current-sensing circuit 1334. In one extreme, a single current-sensing circuit is used for the entire display. Multiplexing the VDD/SENSE pins to the

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sensing circuits in this manner reduces the complexity of the external circuitry, but at the expense of added display measurement time.

Since normal display operation must be interrupted in order to perform pixel measurement cycles, pixel measurements should be scheduled  
5 in a manner that will least disrupt the viewer. Since the pixel parameters change slowly, a given pixel does not need to be measured frequently, and measurement cycles can be spread over a long period of time.

While it is not necessary for all pixels to be measured at the same time, it is advantageous to do so in order to avoid nonuniformity due to  
10 variable measurement lag. This can be accomplished by measuring all pixels rapidly when the display module is turned "on", or when it is turned "off". Measuring pixels when the display module is turned "off" does not interfere with normal operation, but may have the disadvantage that after a long "off" period, the stored pixel parameters may no longer ensure  
15 uniformity. However, if an uninterrupted power source is available (e.g., in screen saver mode), measurement cycles can be performed periodically while the display is "off" (from the user's point of view). Of course, any option that does not include a rapid measurement of all pixels when the display module is turned "on", requires that nonvolatile memory be available for storing  
20 measurement information while power is "off".

If pixel measurement information is available, compensation or calibration of the data voltages can be applied to the display to correct for various sources of display nonuniformity. For example, compensation of the data voltages can be performed to account for transistor threshold-voltage  
25 variations and OLED turn-on voltage variations. As such, the discussion below describes a plurality of methods that are capable of compensating the above sources of display nonuniformity, including other sources of display nonuniformity as well. By using these methods, a display with several sources of nonuniformity, some of them severe, can still provide a uniform,  
30 high-quality displayed image.

For the purpose of describing the present compensation methods, it is assumed that the pixel structure of FIG. 2 is employed in a display.



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However, it should be understood that the present compensation methods can be adapted to a display employing any other pixel structures.

Referring to FIG. 2, the stored voltage on Node A is the gate voltage of N2, and thus establishes a current through N2 and through the LED. By  
 5 varying the gate voltage on N2, the LED current can be varied. Consider the relationship between the gate voltage on N2 and the current through the LED. The gate voltage  $V_g$  can be divided into two parts, the gate-to-source voltage  $V_{gs}$  of N2 and the voltage  $V_{diode}$  across the LED:

$$10 \quad V_g = V_{gs} + V_{diode} \quad (2)$$

For an MOS transistor in saturation the drain current is approximately:

$$I = \frac{k}{2} (V_{gs} - V_t)^2 \quad (3)$$

15

where  $k$  is the device transconductance parameter and  $V_t$  is the threshold voltage. (For operation in the linear region, see below.) Therefore:

$$V_{gs} = \sqrt{\frac{2I}{k}} + V_t \quad (4)$$

20

The forward current through the OLED is approximately:

$$I = AV_{diode}^m \quad (5)$$

25 where  $A$  and  $m$  are constants (See Burrows et al., J. Appl. Phys. 79 (1996)).  
 Therefore:

$$V_{diode} = \sqrt{\frac{I}{A}} \quad (6)$$

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Thus, the overall relation between the gate voltage and the diode current is:

$$V_g = V_t + \sqrt{\frac{2I}{k}} + \sqrt{\frac{I}{A}} \quad (7)$$

It should be noted that other functional forms can be used to  
 5 represent the OLED I-V characteristic, which may lead to different  
 functional relationships between the gate voltage and the diode current.  
 However, the present invention is not limited to the detailed functional form  
 of the OLED I-V characteristic as disclosed above, and as such, can be  
 adapted to operate for any diode-like characteristic.

10 The luminance L of an OLED is approximately proportional to its  
 current I, with the constant of proportionality being fairly stable and  
 uniform across the display. Typically, the display is visually uniform if  
 well-defined OLED currents can be produced. However, as discussed above,  
 the pixel is programmed with the voltage  $V_g$  and not the current I. The  
 15 problem is based on the observation that TFT parameters  $V_t$  and k will  
 exhibit some initial nonuniformity across a display, as well OLED  
 parameters A and m. Furthermore, it is well known that  $V_t$  increases under  
 bias-temperature stress conditions. The OLED parameter A is directly  
 related to the OLED's turn-on voltage, and is known to decrease under bias  
 20 stress. The OLED parameter m is related to the distribution of traps in the  
 organic band gap, and may also vary over the life of the OLED. Thus, these  
 parameters are expected to be initially nonuniform, and to vary over the life  
 of the display in a manner that depends on the individual bias history of  
 each pixel. Programming the gate voltage without compensating for the  
 25 variations of these parameters will yield a display that is initially  
 nonuniform, with increasing nonuniformity over the life of the display.

In fact, other sources of nonuniformity exists. The gate voltage  $V_g$  is  
 not necessarily equal to the intended data voltage  $V_{data}$ . Instead, gain and  
 offset errors in the data drivers, as well as (data-dependent) feedthrough  
 30 arising from the deselection of N1, may cause these two voltages to be  
 different. These sources of error can also be nonuniform and can vary over

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the life of the display. These and any other gain and offset errors can be addressed by expressing:

$$V_g = BV_{data} + V_0 \quad (8)$$

5

where B and  $V_0$  are a gain factor and an offset voltage, respectively, both of which can be nonuniform. Combining and simplifying equations (7) and (8) produces:

$$V_{data} = V_{off} + C\sqrt{I} + D\sqrt[3]{I} \quad (9)$$

10

where  $V_{off}$ , C, and D are combinations of the earlier parameters.

The present invention provides various compensation methods for correcting the intended (input) data voltage  $V_{data}$  to compensate for variations in  $V_{off}$ , C, D, and m, thereby permitting well-defined OLED currents to be produced in the pixel array. In order to compensate for variations in the parameters  $V_{off}$ , C, D, and m, the external current sensing circuits as described above, collect information about each pixel's parameters, i.e., the current drawn by a single pixel can be measured externally. Using the measured information for the parameters  $V_{off}$ , C, D, and m, the present invention calculates the appropriate data voltages  $V_{data}$  in accordance with equation (9), for establishing the desired OLED currents during normal display operation.

20

Alternatively, it should be noted that an exact calculation of the four parameters  $V_{off}$ , C, D, and m from current measurements is computationally expensive, thereby requiring complicated iterative calculations. However, good approximations can be employed to reduce computational complexity, while maintaining effective compensation.

25

In one embodiment, pixel nonuniformity is characterized using only two parameters instead of four as discussed above. Referring to the pixel's current-voltage characteristic of equation (9), at normal illumination levels,

30

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the  $C\sqrt{I}$  term, associated with  $V_{on}$  of N2, and the  $D\sqrt[4]{I}$  term, associated with  $V_{diode}$ , have roughly the same magnitude. However, their dependence on pixel current is very different. The value of  $m$  is approximately 10, such that at typical illumination levels,  $D\sqrt[4]{I}$  is a much weaker function of  $I$  than  $C\sqrt{I}$ .

For example, a 100 fold (100x) increase in  $I$  results in  $C\sqrt{I}$  increasing by 10 fold (10x), but  $D\sqrt[4]{I}$  increases only 1.58 fold (1.58x) (assuming  $m = 10$ ). Namely, at typical illumination current levels, the OLED's I-V curve is much steeper than the TFT's I- $V_{on}$  curve.

As such, an approximation is made where at typical current levels,  $D\sqrt[4]{I}$  is independent of current, and its pixel-to-pixel variation can be simply treated as an offset variation. While this approximation may introduce some error, the appearance of the overall display will not be significantly degraded. Thus, with a fair degree of accuracy all display nonuniformity can be treated as offset and gain variations. Thus, equation (9) can be approximated as:

$$V_{data} = V_{offset} + C\sqrt{I} \quad (10)$$

where  $V_{offset} = V_{off} + D\sqrt[4]{I}$  now includes  $D\sqrt[4]{I}$ , and  $V_{data}$  and  $C$  vary from pixel to pixel.

FIG. 14 illustrates a flowchart of a method 1400 for initializing the display by measuring the parameters of all the pixels. Method 1400 starts in step 1405 and proceeds to step 1410, where an "off" data voltage is applied to all pixels in a pixel block, except for the pixel of interest.

In step 1420, to determine  $V_{offset}$  and  $C$  for a given pixel of interest, method 1400 applies two data voltages ( $V1$  and  $V2$ ), and the current is measured for each data voltage.

In step 1430, the square root of the currents  $I1$  and  $I2$  are calculated.

In one implementation, a square root table is used in this calculation.

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In step 1440,  $V_{\text{offset}}$  and  $C$  are determined, i.e., two equations are available to solve two variables. In turn, the calculated  $V_{\text{offset}}$  and  $C$  for a given pixel of interest, are stored in a storage, e.g., memory. After all pixels have been measured, the memory contains the two parameters  $V_{\text{offset}}$  and  $C$  for each pixel in the array. These values can be used at a later time to calibrate or adjust  $V_{\text{data}}$  in accordance with equation (10). Method 1400 then ends in step 1455.

It should be noted that the current through the measured pixel should be high enough such that  $D\sqrt{I}$  can be treated as approximately the same at the two measurement points. Preferably, this condition can be satisfied by making one measurement at the highest data voltage that the system can generate, and then the other measurement at a slightly lower data voltage.

Once display initialization has been performed, the raw input video data supplied to the display module can be corrected. It should be noted that the input video data can exist in various formats, e.g., the video data can represent (1) pixel voltages, (2) gamma-corrected pixel luminances, or (3) pixel currents. As such, the use of the stored parameters  $V_{\text{offset}}$  and  $C$  to calibrate or adjust the input video data depends on each specific format.

FIG. 15 illustrates a flowchart of a method 1500 for correcting input video data representing pixel voltages. Method 1500 starts in step 1505 and proceeds to step 1510, where the stored parameters, e.g.,  $V_{\text{offset}}$  and  $C$  are retrieved for a pixel of interest.

In step 1520, method 1500 applies the retrieved parameters to calibrate the input video data. More specifically, it is expected that the input video data are unbiased, i.e., zero volts represents zero luminance, and data greater than zero represent luminance levels greater than zero. Therefore, the voltages can be regarded as equal to  $C_0\sqrt{I}$ , where  $I$  is the desired current and  $C_0$  is a constant, e.g., with a typical value  $10^3 V/\sqrt{A}$ .

To compensate for pixel variations, as input video data enters the display module, the value of  $V_{\text{data}} = V_{\text{offset}} + C\sqrt{I}$  is calculated for each pixel, based on

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the stored values of  $V_{\text{offset}}$  and  $C$ . This calculation consists of multiplying the video data by  $C/C_0$ , and adding  $V_{\text{offset}}$  to the result.

The division by  $C_0$  can be avoided if the video data  $V_{\text{data}}$  has already been scaled by the constant factor  $1/C_0$ . The multiplication by  $C$  can be performed directly in digital logic, or using a look-up table. For example, in the latter case, each value of  $C$  specifies a table where the value of the video data is an index, and the table entries consist of the result of the multiplication. (Alternatively, the roles of  $C$  and the input video data in the look-up table can be reversed.) After the multiplication is performed, rapid addition of  $V_{\text{offset}}$  can be implemented with digital logic.

In step 1530, the resulting voltage  $V_{\text{data}}$ , i.e., the corrected or adjusted input data, is then forwarded to the data driver of pixel array. Method 1500 then ends in step 1535.

In the case of gamma-corrected luminance data, the input video data are proportional to  $L^{0.45}$ , where  $L$  is luminance. This is typical for video data that have been pre-corrected for CRT luminance-voltage characteristics. Since  $L^{0.45} = \sqrt{L}$ , and the OLED luminance is proportional to its current, the data can be treated as proportional to  $\sqrt{I}$ . Thus, the calculation can be performed in the same way as for zero-offset voltage data as discussed above.

FIG. 16 illustrates a flowchart of a method 1600 for correcting input video data representing pixel currents, i.e., luminances. Method 1600 starts in step 1605 and proceeds to step 1610, where the square-root values of the measured current are calculated. Namely, method 1600 is similar to the method 1500 described above, with the exception that the video data representing  $I$  must be processed to yield  $\sqrt{I}$ . As noted above, this operation can be implemented using a table that provides square-root values as needed for deriving the pixel parameters  $V_{\text{offset}}$  and  $C$  from pixel current measurements, as illustrated in FIG. 14. Here, this table is used again to generate  $\sqrt{I}$  from the video data.

Then, the data correction steps 1610-1645 of method 1600 are identical to the method 1500 as described above, with the exception that the

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square root of the input data is multiplied by  $C$  in step 1630 and then followed by an addition of  $V_{\text{offset}}$  to yield the corrected data voltage.

Alternatively, in another embodiment, pixel nonuniformity is characterized using only one parameter instead of two or four parameters as discussed above. Namely, an additional simplification is made such that pixel nonuniformity is characterized using a single parameter.

More specifically, in many cases the pixel-to-pixel variation in the gain factor  $C$  is small, leaving  $V_{\text{offset}}$  as the only significant source of nonuniformity. This occurs when the TFT transconductance parameter  $k$  and the voltage gain factor  $B$  are uniform. In this case, it is sufficient to determine each pixel's  $V_{\text{offset}}$ . Then, data correction does not involve multiplication (since the gain factor  $C$  is assumed to be uniform), but only involves addition of the offset parameter.

This one-parameter approximation is similar to the above autozeroing OLED pixel structures. The present one-parameter compensation method should produce satisfactory display uniformity, while reducing computational expense. However, if maintaining display uniformity is very important to a particular display application, then the above described two or four-parameter methods can be employed at the expense of increasing computational complexity and expense.

Again, for one-parameter extraction and data correction, the display initialization process depends on the format of the data. The single-parameter method can be used to initialize the display and to correct video data for the cases of video data representing (1) pixel voltages, (2) pixel currents, and (3) gamma-corrected pixel luminances.

FIG. 17 illustrates a flowchart of a method 1700 for initializing the display by measuring the parameters of all the pixels. Method 1700 starts in step 1705 and proceeds to step 1710, where an "off" data voltage is applied to all pixels in a pixel block, except for the pixel of interest.

In step 1720, to determine  $V_{\text{offset}}$  and  $C$  for a given pixel of interest, method 1700 applies two data voltages ( $V_1$  and  $V_2$ ), and the current is measured for each data voltage.

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In step 1730, the square root of the currents I1 and I2 are calculated. In one implementation, a square root table is used in this calculation.

It should be noted that since the value of C is supposed to be uniform, then ideally it can be determined by making a two-point measurement on a single pixel anywhere in the display. However, this is questionable, since the pixel of interest may be unusual. Thus, a two-point measurement is made on every pixel.

In step 1740, the average C is determined. Namely, using a table to calculate  $\sqrt{I}$  for each current measurement, an average value of C for the display can be calculated.

In step 1750,  $V_{offset}$  is determined for each pixel from its current measurements based on the average C. In this manner, small variations in C across the display are partially compensated by the calculated  $V_{offset}$ . For reasons given above, it is preferable to make each pixel's current measurement at the highest possible data voltage.

Finally, in step 1760, each pixel's  $V_{offset}$  is stored in a storage, e.g., memory. Method 1700 then ends in step 1765.

FIG. 18 illustrates a flowchart of a method 1800 for correcting input video data representing pixel voltages. Method 1800 starts in step 1805 and proceeds to step 1810, where the stored parameters, e.g.,  $V_{offset}$  is retrieved for a pixel of interest.

In step 1820, method 1800 applies the retrieved parameter  $V_{offset}$  to calibrate the input video data. More specifically, the value of  $V_{data} = V_{offset} + V_{data}$  is calculated for each pixel, based on the stored value of  $V_{offset}$ .

In step 1830, the resulting voltage  $V_{data}$ , i.e., the corrected or adjusted input data, is then forwarded to the data driver of pixel array. Method 1800 then ends in step 1835.

FIG. 19 illustrates a flowchart of a method 1900 for initializing the display by measuring the parameters of all the pixels for the situation where the video data represents pixel currents. It should be noted that



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method 1900 is very similar to method 1700 as discussed above. The exception arises when method 1900 incorporates an additional step 1950, where a calculated average value of  $C$  is used to generate a table of zero-offset data voltage vs. pixel current. From this point forward in the

5 initialization and data correction processes, square root operations can be avoided by using this table. The table is expected to provide a more accurate representation of the pixel's current-voltage characteristics than the square-root function. The table is then stored in a storage, e.g., a memory for later use. Then the individual pixel current measurements are

10 used as indexes to enter this table, and individual pixel offsets  $V_{offset}$  are determined.

FIG. 20 illustrates a flowchart of a method 2000 for correcting input video data represented in pixel currents, i.e., luminances. Method 2000 starts in step 2005 and proceeds to step 2010, where the current pixel of

15 interest's  $V_{offset}$  is retrieved from storage.

In step 2020, the zero-offset data voltage vs. pixel current table is used to obtain a zero-offset data voltage from the input video data current. This zero-offset data voltage is added to the retrieved  $V_{offset}$  in step 2030. Finally, in step 2040, the corrected or adjusted input video data, is then

20 forwarded to the data driver of the pixel array.

In sum, as video data are introduced into the display module, the zero-offset data voltage corresponding to each current is looked up in the V-I table. Then the stored pixel offset is added to the zero-offset voltage, and the result is the input to the data driver. Method 2000 then ends in step

25 2045.

FIG. 21 illustrates a flowchart of a method 2100 for initializing the display by measuring the parameters of all the pixels for the situation where the video data represents gamma-corrected luminance data. It should be noted that method 2100 is very similar to method 1900 as

30 discussed above. The exception arises in step 2150 of method 2100, where a calculated average value of  $C$  is used to generate a table of zero-offset data voltage vs. the square root of the pixel current. Namely, the video data can

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be approximated as representing  $\sqrt{I}$ . As such, the average value of C is used to create a zero-offset table of  $V_{data}$  vs.  $\sqrt{I}$ , and this table is saved in a storage such as a memory.

FIG. 22 illustrates a flowchart of a method 2200 for correcting input video data represented in gamma-corrected luminance data. It should be noted that method 2200 is very similar to method 2000 as discussed above. The only exception arises in the zero-offset table of  $V_{data}$  vs.  $\sqrt{I}$ . Thus, in sum, incoming video data are used to look up the zero-offset data voltages, and stored pixel offsets are added to these voltages.

It should be noted that the above description assumes that the OLED drive transistor N2 is operated in saturation. Similar compensation methods can be used, if N2 is operated in the linear region. In that case, the pixel's current voltage characteristic is expressed as:

$$V_{data} = V_{off} + C(I)I + D\sqrt{I} \quad (11)$$

where  $C(I)$  is a weak function of I. Again, the  $D\sqrt{I}$  term can be incorporated in  $V_{off}$  if the current is sufficiently high, such that only an offset term and a gain factor need to be determined as discussed above. However, the one-parameter approximation, where only the offset voltage is regarded as nonuniform, is not anticipated to be as accurate as the above one-parameter approximation for the saturation case, because now the gain factor  $C(I)$  contains the nonuniform OLED parameters A and m. Thus, the two-parameter correction method will likely perform significantly better than the one-parameter correction method, if N2 is operated in the linear region.

FIG. 23 illustrates a block diagram of a system 2300 employing a display 2320 having a plurality of active matrix LED pixel structures 300, 500, or 700 of the present invention. The system 2300 comprises a display controller 2310 and a display 2320.

More specifically, the display controller can be implemented as a general purpose computer having a central processing unit CPU 2312, a

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memory 2314 and a plurality of I/O devices 2316 (e.g., a mouse, a keyboard, storage devices, e.g., magnetic and optical drives, a modem, A/D converter, various modules, e.g., measurement module 1330 as discussed above, and the like). Software instructions (e.g., the various methods described above) for activating the display 2320 can be loaded, e.g., from a storage medium, into the memory 2314 and executed by the CPU 2312. As such, the software instructions of the present invention can be stored on a computer-readable medium.

The display 2320 comprises a pixel interface 2322 and a plurality of pixels (pixel structures 300, 500, or 700). The pixel interface 2322 contains the necessary circuitry to drive the pixels 300, 500, or 700. For example, the pixel interface 2322 can be a matrix addressing interface as illustrated in FIG. 1 and may optionally include additional signal/control lines as discussed above.

Thus, the system 2300 can be implemented as a laptop computer. Alternatively, the display controller 2310 can be implemented in other manners such as a microcontroller or application specific integrated circuit (ASIC) or a combination of hardware and software instructions. In sum, the system 2300 can be implemented within a larger system that incorporates a display of the present invention.

Although the present invention is described using NMOS transistors, it should be understood that the present invention can be implemented using PMOS transistors, where the relevant voltages are reversed.

Although various embodiments which incorporate the teachings of the present invention have been shown and described in detail herein, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings.

What is claimed is:

1. A display comprising at least one pixel, said pixel comprising:
  - a first transistor having a gate, a source and a drain, where said gate
  - 5 is for coupling to a first select line;
  - a capacitor having a first and second terminals, where said drain of said first transistor is coupled to said first terminal of said capacitor;
  - a second transistor having a gate, a source and a drain, where said drain of said first transistor is coupled to said drain of said second
  - 10 transistor, where said gate of said second transistor is for coupling to an autozero line;
  - a third transistor having a gate, a source and a drain, where said source of said third transistor is coupled to said drain of said second transistor, where said gate of said third transistor is for coupling to a second
  - 15 select line;
  - a fourth transistor having a gate, a source and a drain, where said drain of said fourth transistor is coupled to said source of said second transistor, where said gate of said fourth transistor is coupled to said source of said first transistor;
  - 20 a fifth transistor having a gate, a source and a drain, where said drain of said fifth transistor is coupled to said drain of said third transistor, where said gate of said fifth transistor is coupled to said source of said first transistor; and
  - a light element having two terminals, where said source of said
  - 25 fourth transistor and said source of said fifth transistor are coupled to one of said terminal of said light element.
2. The display of claim 1, wherein said light element is an organic light emitting diode (OLED).
- 30 3. The display of claim 1, wherein said transistors are thin film transistors constructed from amorphous-silicon.

4. The display of claim 1, wherein said second select line is an autozero line from a previous row.

- 5 5. A display comprising at least one pixel, said pixel comprising:  
a first transistor having a gate, a source and a drain, where said gate  
is for coupling to a select line;  
a capacitor having a first and second terminals, where said drain of  
said first transistor is coupled to said first terminal of said capacitor;  
10 a second transistor having a gate, a source and a drain, where said  
drain of said first transistor is coupled to said drain of said second  
transistor, where said gate of said second transistor is for coupling to an  
autozero line;  
a diode having a first and second terminals, where said source of said  
15 second transistor is coupled to said first terminal of said diode, where said  
second terminal of said diode is for coupling to an illuminate line;  
a third transistor having a gate, a source and a drain, where said  
drain of said third transistor is coupled to said first terminal of said diode,  
where said gate of said third transistor is coupled to said source of said first  
20 transistor; and  
a light element having two terminals, where said source of said third  
transistor is coupled to one of said terminal of said light element.

6. The display of claim 5, wherein said diode is a Schottky diode.

25

7. A display comprising at least one pixel, said pixel comprising:  
a first transistor having a gate, a source and a drain, where said gate  
is for coupling to a first select line;  
a capacitor having a first and second terminals, where said drain of  
30 said first transistor is coupled to said first terminal of said capacitor;  
a second transistor having a gate, a source and a drain, where said  
source of said first transistor is coupled to said source of said second

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transistor, where said gate of said second transistor is for coupling to an autozero line;

a third transistor having a gate, a source and a drain, where said source of said third transistor is coupled to said drain of said second transistor, where said gate of said third transistor is for coupling to a second select line;

a fourth transistor having a gate, a source and a drain, where said drain of said fourth transistor is coupled to said source of said third transistor, where said gate of said fourth transistor is coupled to said source of said first transistor;

a fifth transistor having a gate, a source and a drain, where said drain of said fifth transistor is coupled to said drain of said third transistor, where said gate of said fifth transistor is coupled to said source of said first transistor; and

a light element having two terminals, where said source of said fourth transistor and said source of said fifth transistor are coupled to one of said terminal of said light element.

8. The display of claim 7, wherein said light element is an organic light emitting diode (OLED).

9. The display of claim 7, wherein said second select line is an autozero line from a previous row.

10. A display comprising:

at least one autozeroing pixel structure;

an autozero line, coupled to said autozeroing pixel structure, for allowing said autozeroing pixel structure to perform autozeroing; and

a second line, coupled to said autozeroing pixel structure, for carrying a voltage to said autozeroing pixel structure that permits a range of autozero voltages to be extended.

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11. A method of illuminating a display having at least one pixel, where said pixel contains a circuit for controlling application of energy to a light element, said method comprising the steps of:

- (a) autozeroing the pixel;
- 5 (b) loading data onto said pixel via a data line; and
- (c) illuminating said light element in accordance with said stored data.

12. The method of claim 11, further comprising the step of:

- 10 (a') precharging said pixel prior to said autozeroing step (a).

13. The method of claim 11, wherein said autozeroing step (a) comprises the step of applying a reference black level.

15 14. A method of illuminating a display having at least one pixel, said method comprising the steps of:

- (a) measuring a pixel parameter of said pixel;
- (b) adjusting an input pixel data in accordance with said measured pixel parameter; and
- 20 (c) illuminating said pixel in accordance with said adjusted input pixel data.

15. The method of claim 14, wherein said measuring step (a) measures externally a current drawn by said pixel.

25

16. The method of claim 15, wherein said adjusting step (b) adjusts said pixel data by using said measured pixel parameter to determine a voltage offset ( $V_{offset}$ ) parameter.

30 17. The method of claim 16, wherein said adjusting step (b) further adjusts said pixel data by using said measured pixel parameter to determine a gain factor (C) parameter.

18. A system comprising:  
a display controller; and  
a display, coupled to said display controller, where said display  
5 comprises a plurality of pixels, where each pixel comprises:  
a first transistor having a gate, a source and a drain, where said gate  
is for coupling to a first select line;  
a capacitor having a first and second terminals, where said drain of  
said first transistor is coupled to said first terminal of said capacitor;  
10 a second transistor having a gate, a source and a drain, where said  
source of said first transistor is coupled to said source of said second  
transistor, where said gate of said second transistor is for coupling to an  
autozero line;  
a third transistor having a gate, a source and a drain, where said  
15 source of said third transistor is coupled to said drain of said second  
transistor, where said gate of said third transistor is for coupling to a second  
select line;  
a fourth transistor having a gate, a source and a drain, where said  
drain of said fourth transistor is coupled to said source of said third  
20 transistor, where said gate of said fourth transistor is coupled to said source  
of said first transistor;  
a fifth transistor having a gate, a source and a drain, where said  
drain of said fifth transistor is coupled to said drain of said third transistor,  
where said gate of said fifth transistor is coupled to said source of said first  
25 transistor; and  
a light element having two terminals, where said source of said  
fourth transistor and said source of said fifth transistor are coupled to one of  
said terminal of said light element.
- 30 19. A system comprising:

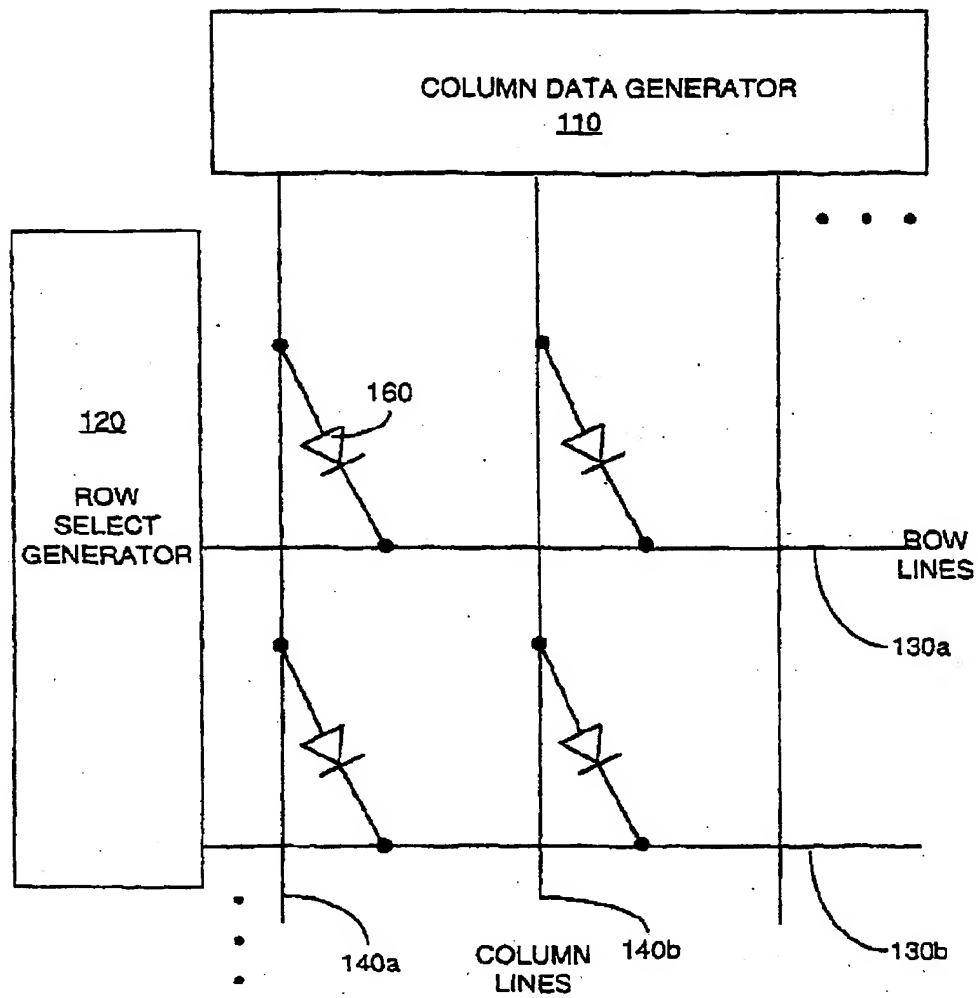


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a display controller having a measurement module for measuring a pixel parameter of a pixel and a storage for storing said measured pixel parameter; and

5 a display, coupled to said display controller, for displaying an input pixel data that is adjusted in accordance with said stored pixel parameter.

20. The system of claim 19, wherein said measurement module comprises a current sensing circuit for measuring a current drawn by said pixel.

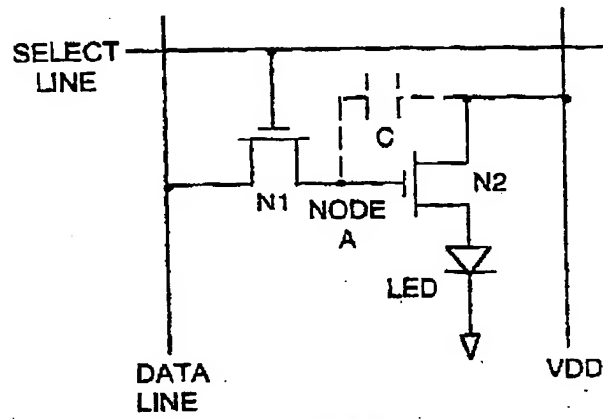
100

(PRIOR ART)

FIG. 1

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200



(PRIOR ART)

FIG. 2

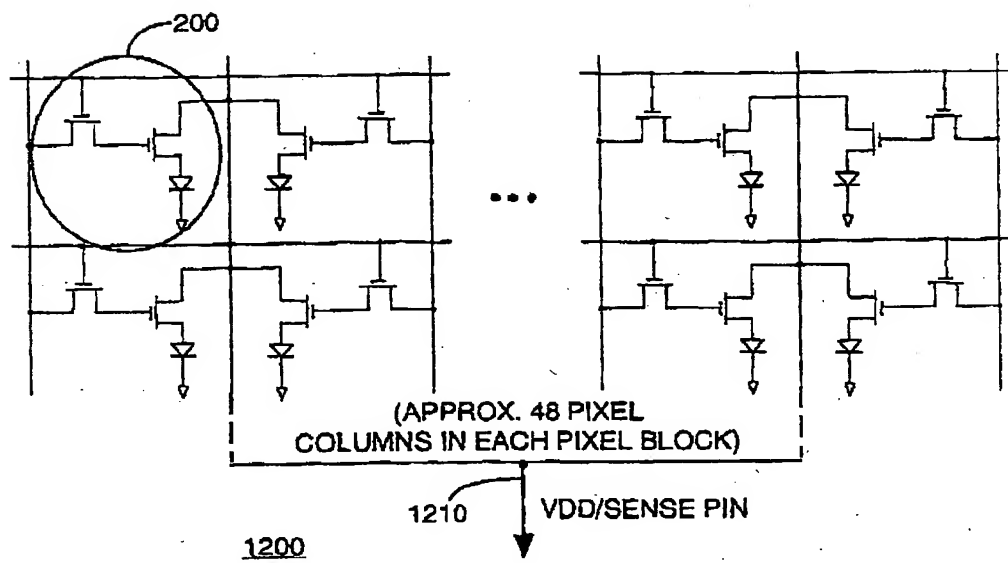


FIG. 12

FIG. 3



FIG. 4

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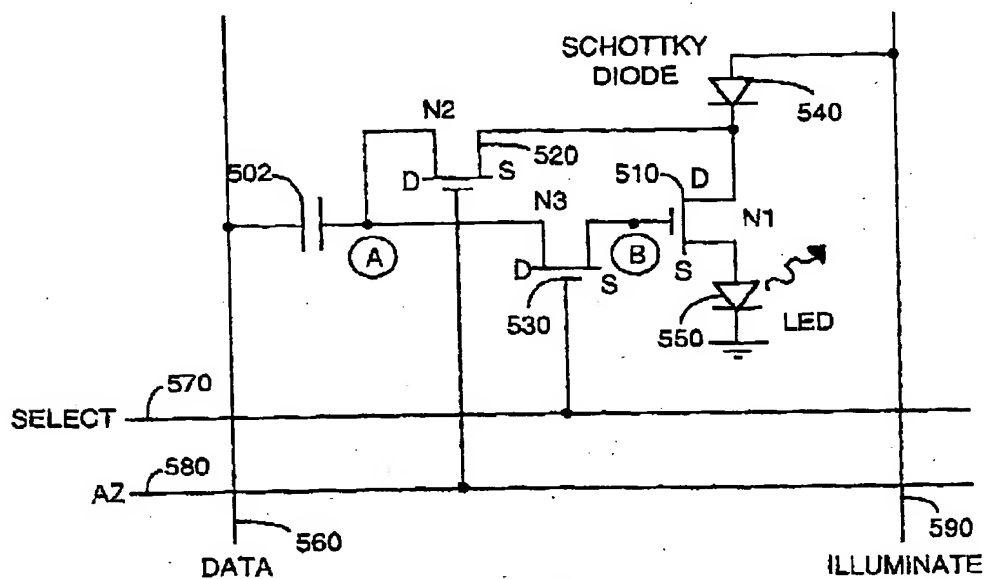


FIG. 5

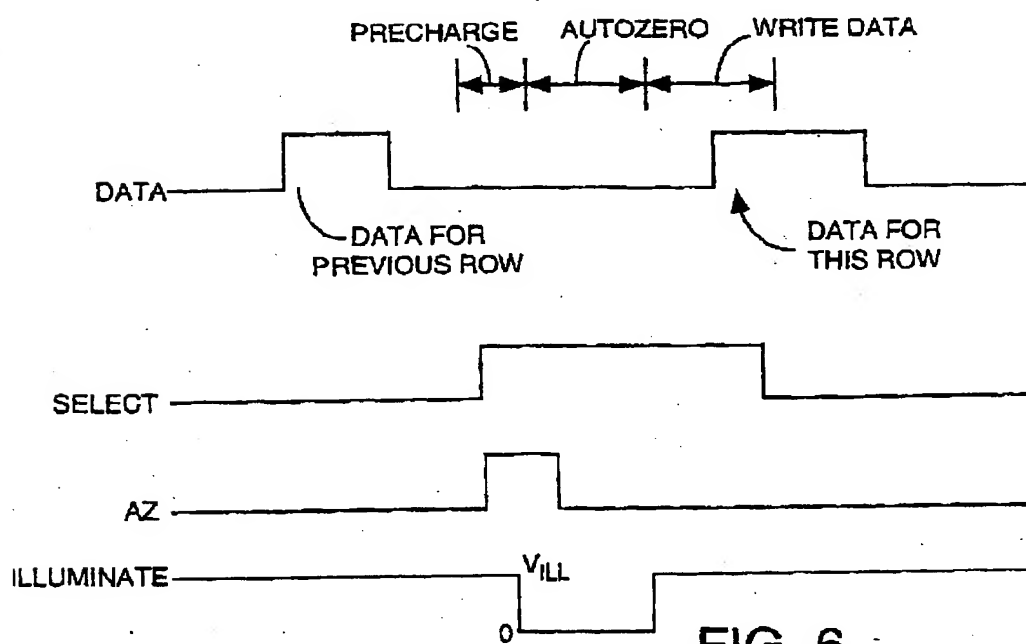


FIG. 6

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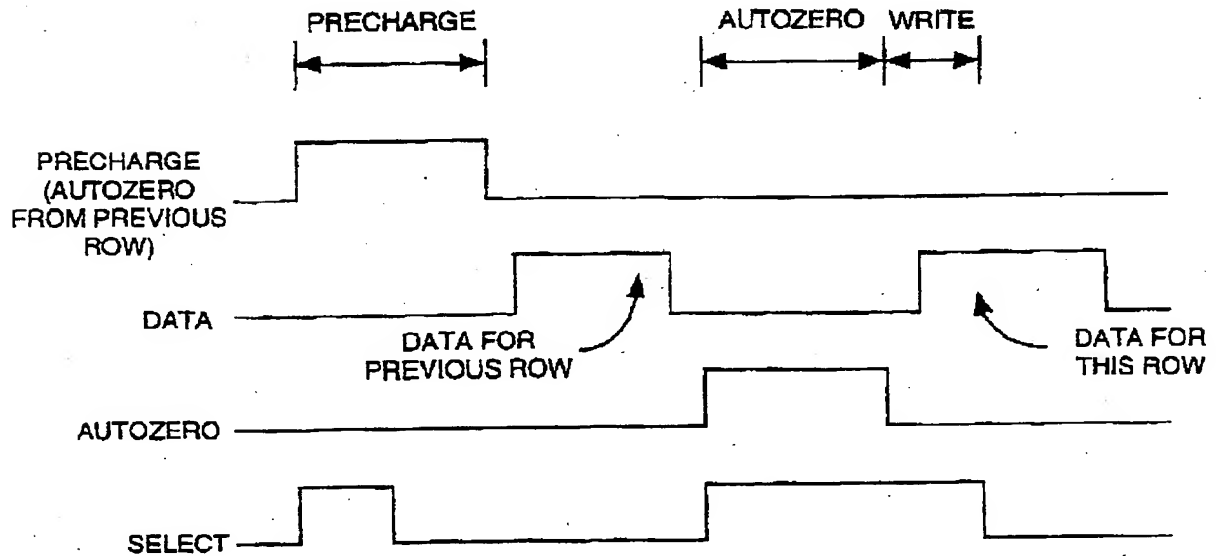
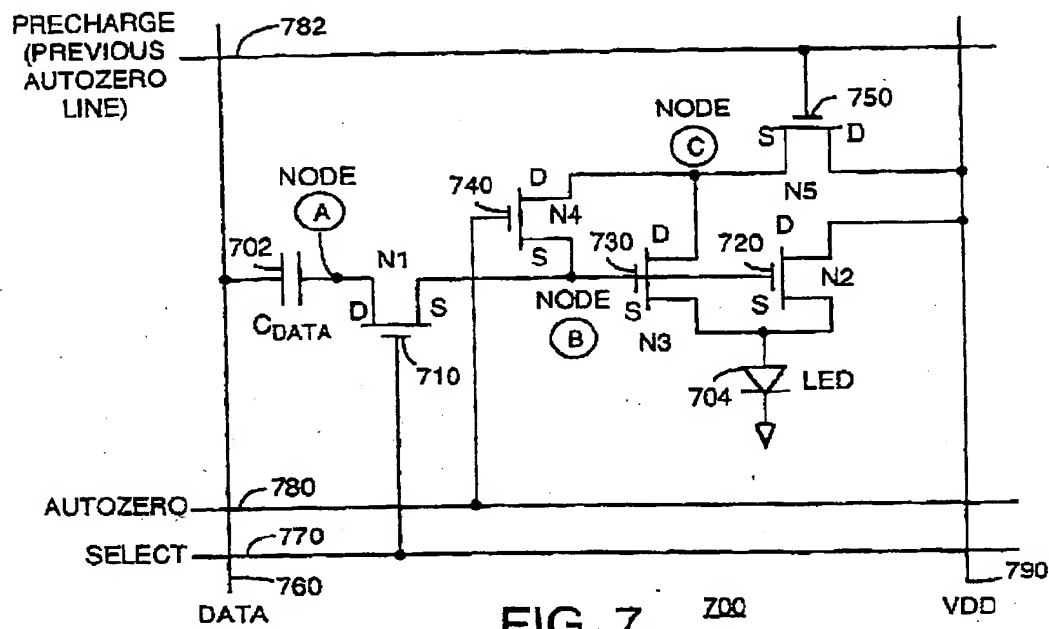


FIG. 8

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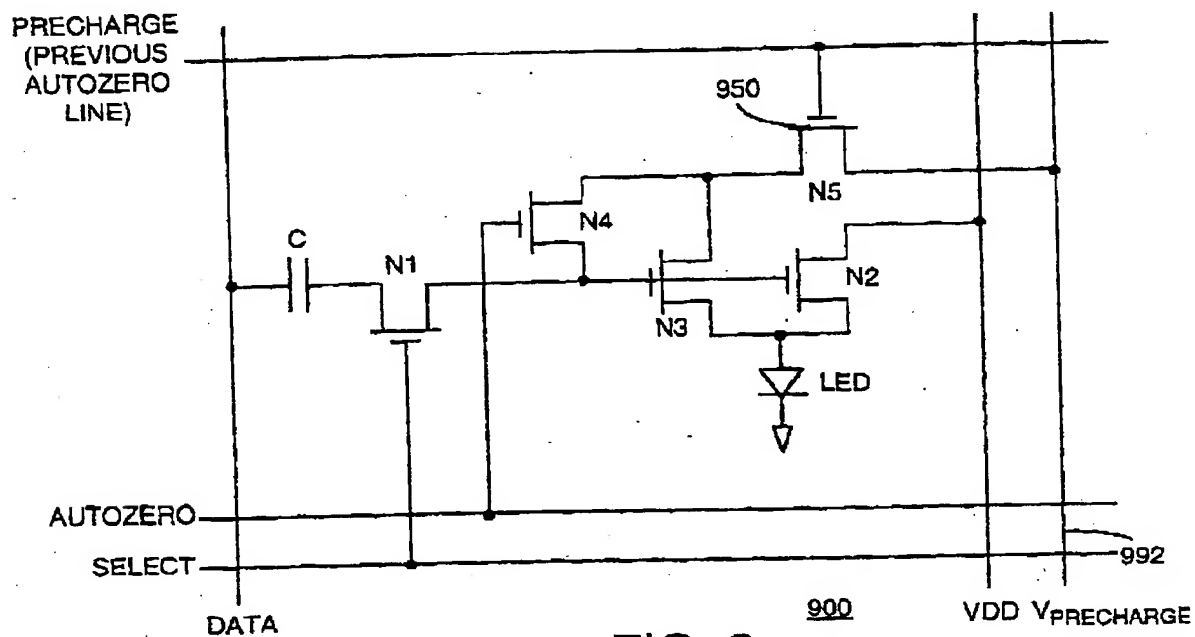
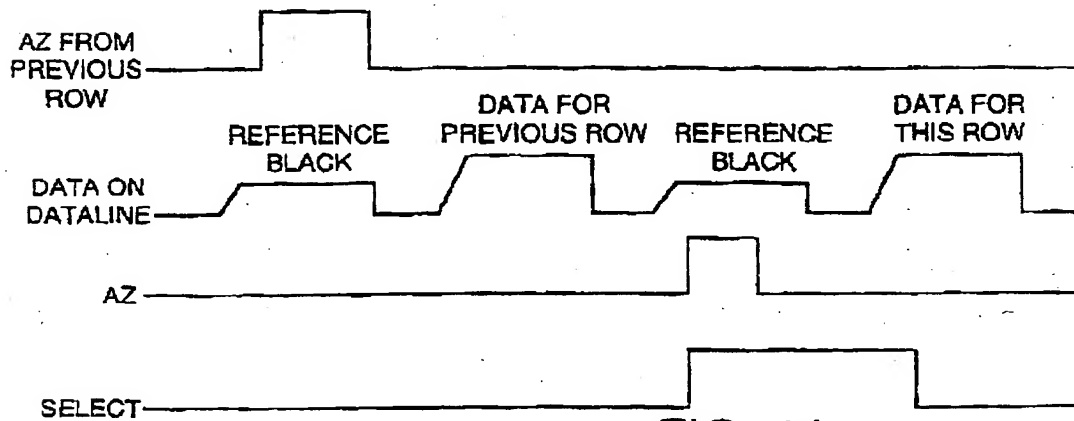
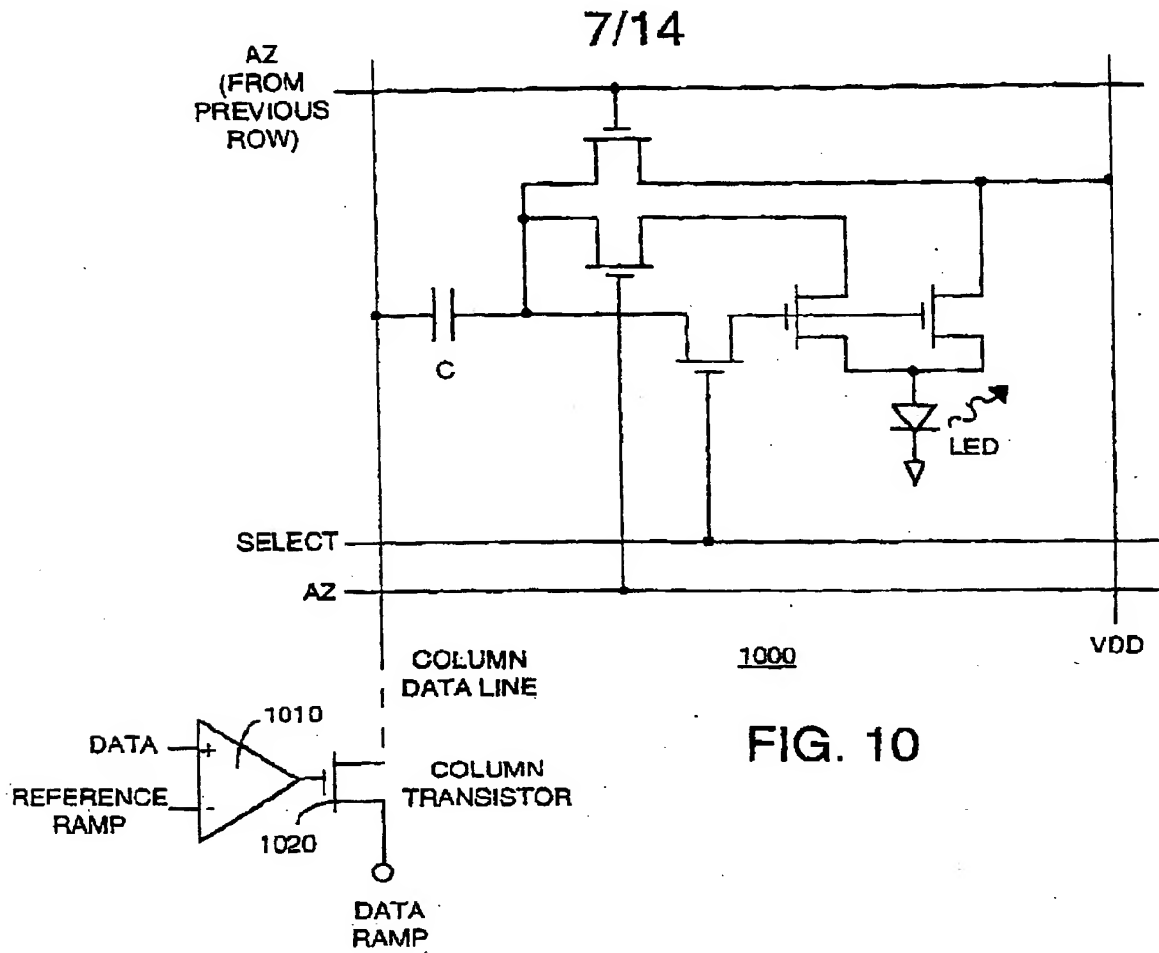


FIG. 9





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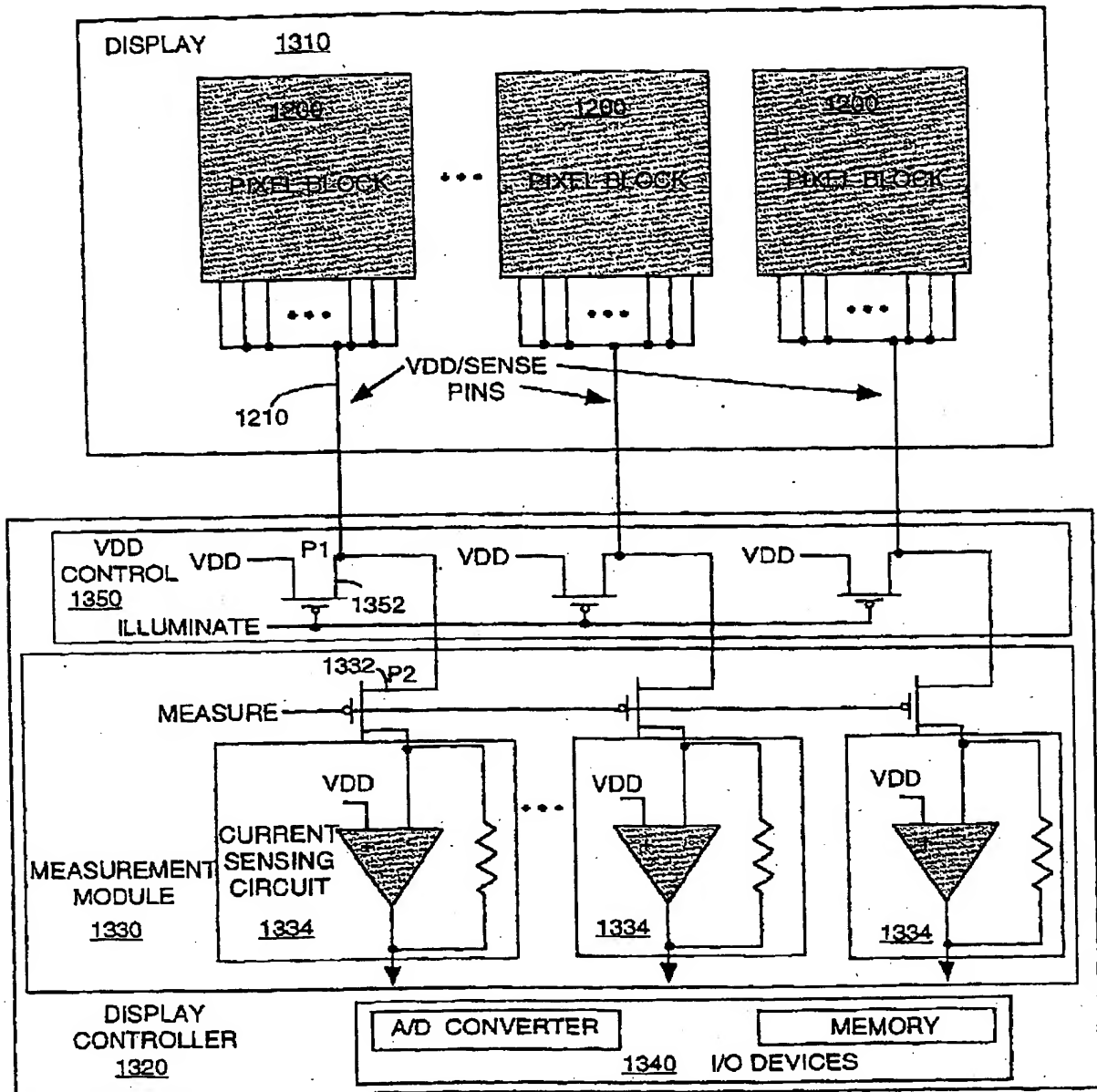


FIG. 13

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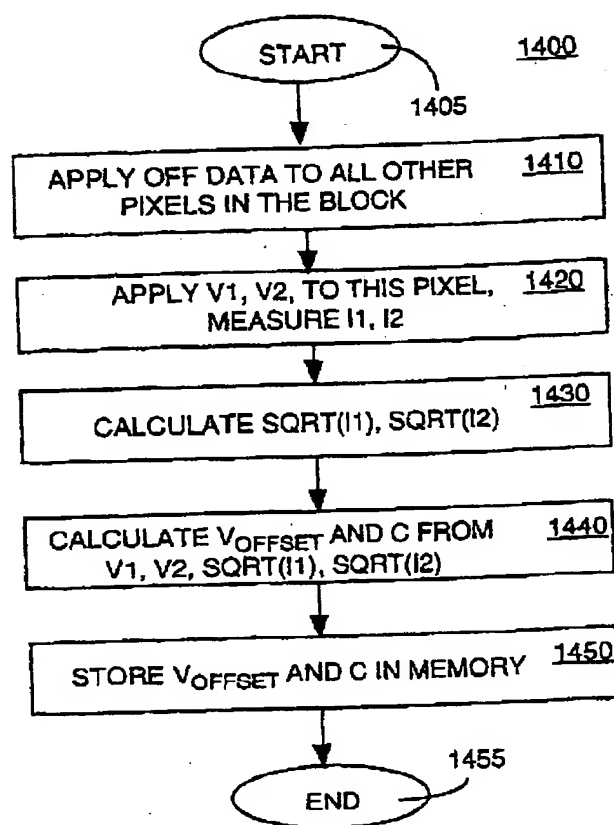


FIG. 14

10/14

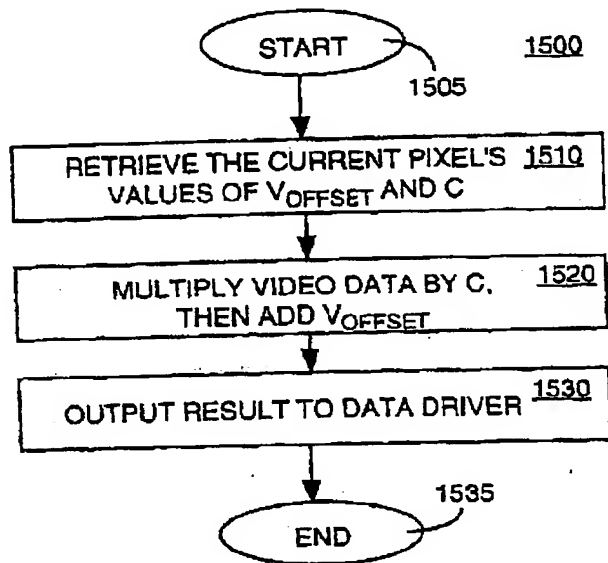


FIG. 15

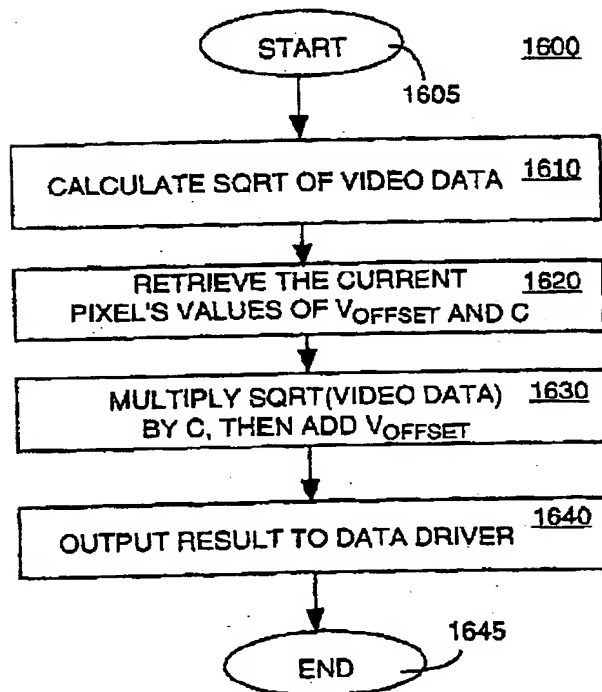


FIG. 16

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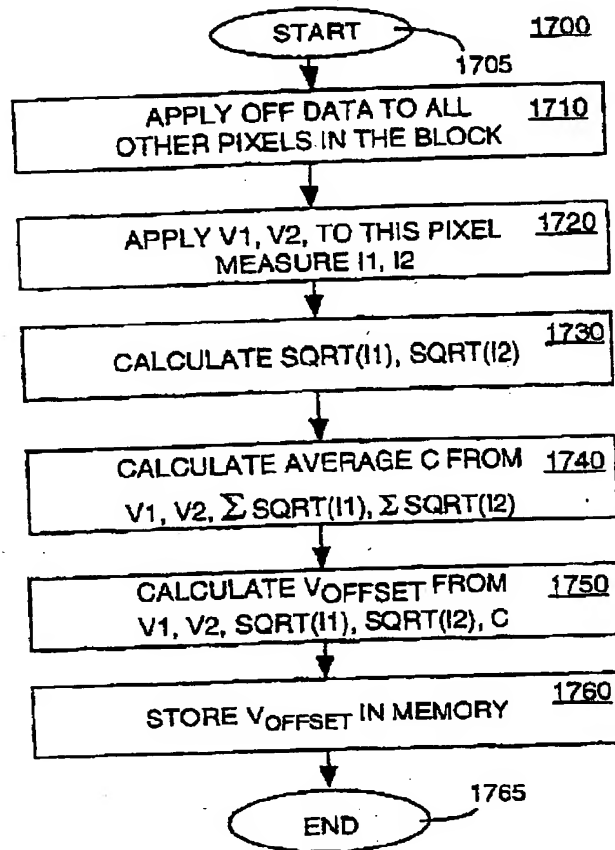


FIG. 17

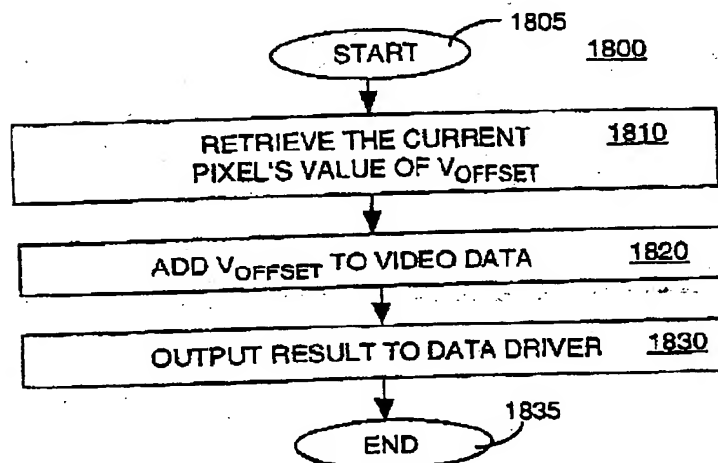


FIG. 18

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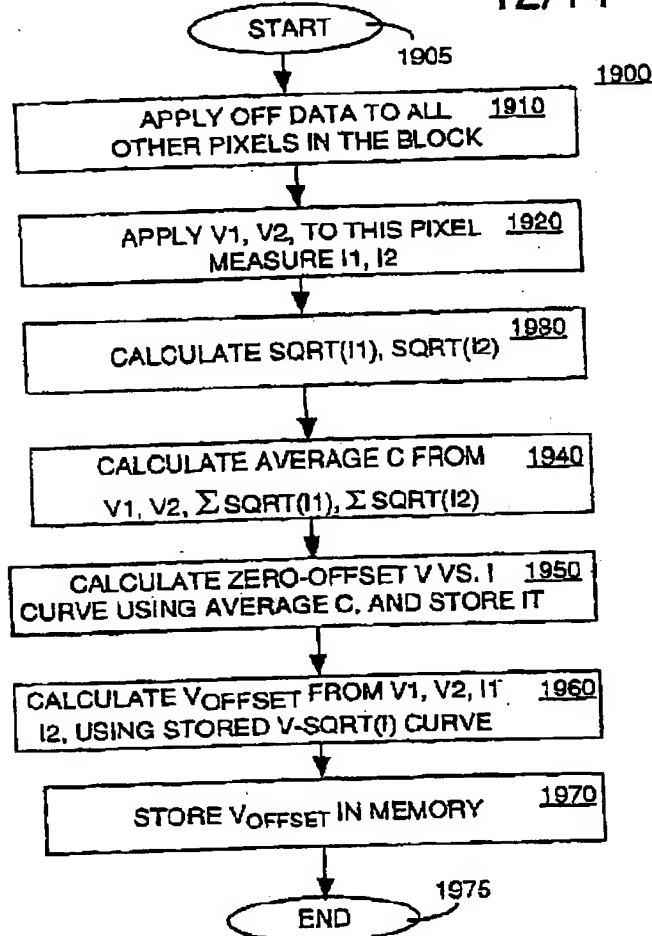


FIG. 19

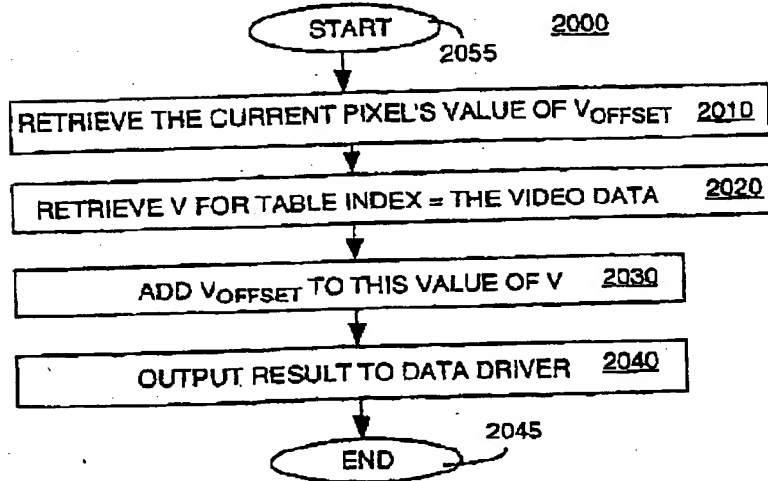


FIG. 20

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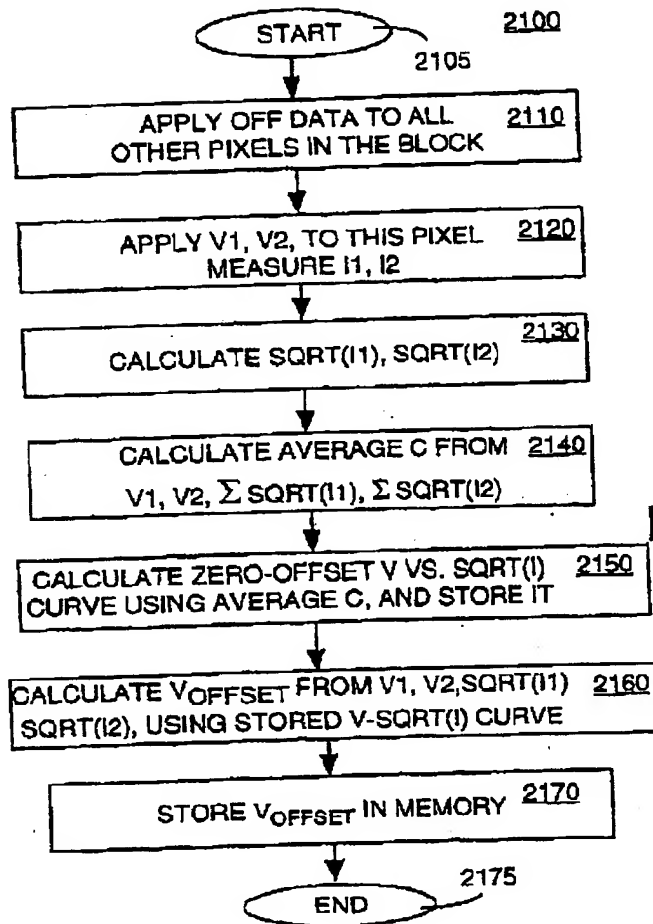


FIG. 21

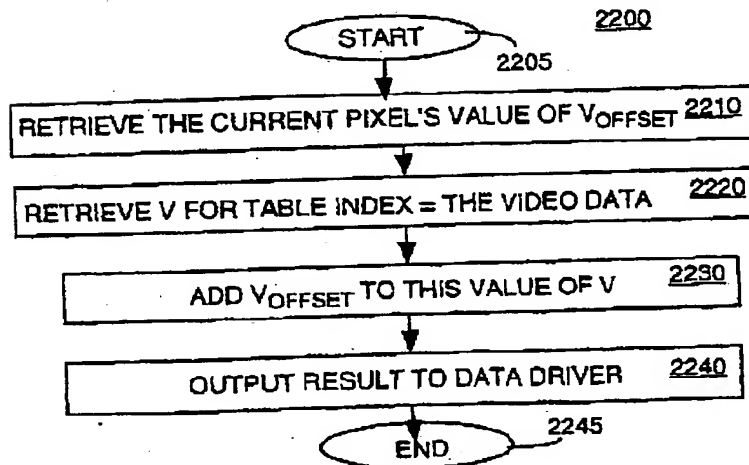


FIG. 22

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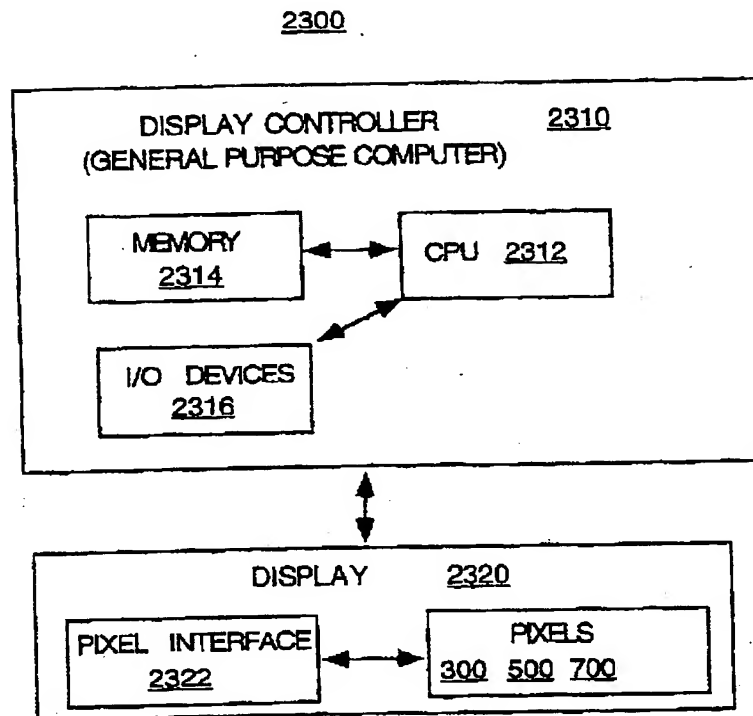


FIG. 23

**Abstract of the Disclosure**

LED pixel structures and methods that improve brightness uniformity by reducing current nonuniformities in a light-emitting diode of the pixel structures are disclosed.